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TRUST MODELLING THROUGH SOCIAL SCIENCES

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TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Kalash, Abeer M.S., Purdue University, December 2014. Trust Modelling through Social Sciences. Major Professor: Arjan Durresi.

In today's fast paced world, people have become increasingly interested in online communication to facilitate their lives and make it faster. This goes on from simple social interactions to more advanced actions like shopping on the internet. The presence of such activities makes it crucial for people to use their common sense and judgment to process all this information and evaluate what/who they trust and what/whom they do not. This process would have been much easier if the number of people in such networks is really small and manageable. However, there are millions of users who are hooked online every day. This makes the person very overwhelmed with his trusting decision, especially when it comes to interacting with strangers over the internet, and/or buying personal items, especially expensive ones. Therefore, many trust models have been proposed by computer scientists trying to evaluate and manage the trust between users using different techniques and combining many factors.

What these computer scientists basically do is coming up with mathematical formulas and models to express trust in online networks and capture its parameters. However, social scientists are the people better trained to deal with concepts related to human behaviors and their cognitive thinking such as trust.

Thus, in order for computer scientists to support their ideas and get a better insight about how to direct their research, people like social scientists should contribute.

With this in mind, we realized in our group work the importance of such contribution, so we came up with the idea of my research work. In my search, I tried to find how these social scientists think and tackle a dynamic notion like trust, so we can use their findings in order to enhance our work and trust model.

Through the chapters, I will discuss an already developed trust model that uses measurement theory in modeling trust. I will refer back to this model and see how other social scientists dealt with some of the issues encountered by the model and its functionality. Some small experiments have been done to show and compare our results with social scientists results for the same matter.

One of the most important and controversial point to be discussed from social scientists point of view is whether trust is transitive or not. Other points to be discussed and supported by social scientists' research include aggregation, reputation, timing effects on trust, reciprocity, and experience effects on trust. Some of these points are classified into trust mapping categories and others are related to trust management or decision making stages.

In sum, this work is a multidisciplinary study of trust whose overall goal is to enhance our work and results, as computer scientists.

CHAPTER 1. INTRODUCTION

1.1 Introduction

Suppose you are about to buy a new car, and you have no experience about car markets whatsoever. You contact a friend whom you trust asking for his advice. If your friend is expert in car markets, he directs you in the right way to go; otherwise he will refer you to someone else whom he trusts. Now are you going to trust his friend in this matter? How about the scenario where that suggested friend consults his friend as well? Now the chain of trust is even longer. How will you proceed in your trust decision?

This is just a simple example of unlimited ones about trust scenarios and its complex choices options between people's social interactions. In the essence of these social interactions between people, trust is a very essential factor that they depend on [1], especially when this trust decision has some serious consequences, i.e. related to health issues [2].

Now, all the scenarios above will become even much more complicated when you have to do all the evaluation online, where there are huge amount of information that is hard to process by human [1]. Users in this case may end up interacting with others they never saw before or with institutions they did not hear about [3]. This makes it very difficult to decide whether the information in hand is really credible, and whether the other person you are dealing with is really trustworthy [3]. The rampant widespread of

online interaction makes it very important to take some precautious into consideration when dealing with people and services there, and trust concept comes into the picture in such scenarios.

Trust and trustworthiness are recognized as very vital keys in many different social and financial fields [4]. In [4] for example, they mentioned a very concrete example about the role of trust in social networks in the revolution that happened in Egypt where people arranging to that day depended on Facebook and Twitter to organize their movements. However, they had to have some kind of trust between them and the people to whom they send the invitations to arrange that uprising [4]. Otherwise, they would have been in a very risky situation for participating in such actions against the regime, especially if they had communicated their real opinions and plans with untrusted people who leaked out the news to the higher authority [4].

1.2 The Need for Trust Models

All the scenarios above show the role that the online world plays in people's daily lives and how it has become the new trend over the last recent years. This goes from social networks such as Facebook, Twitter to shopping and e-commerce ones such as eBay, Amazon, Yelp, and Epinions, etc. The number of social networks went from 125 to 223 between December 2004 to 2006, and the number of their users have also increased dramatically and still growing [5, p.31], [6]. This increase is not just in the numbers of participants but also in the number of links between them making the network management a very hard task to do [7].

Such situations present some kind of hazards since users participating in the online process are not there in person, so there is a bigger chance for deception and/or misbehaving [8]. In short, it is very hard to handle and process all this information and manage trusting decision for millions of users scattered everywhere online. Thus, the need and importance of trust management systems and frameworks has spiked more, and the research in this area has been a hot topic for computer scientists. Each paper tries to introduce different factors and metrics to capture trust in its different state and occurrence.

1.3 Thesis Objective and Contributions

So depending on this pressing need, computer scientists have worked hard and proposed many trust models to help in the management of online trust, so where does the problem lie?

As we all know, computer scientists are people of numbers, formulas and calculations. In other words, they use mathematical tools in analyzing a situation in order to formalize it and express it in a scientific way. However, since trust is a subjective concept in nature, it has many definitions and meanings in different fields that until today there is still no one unique definition used by all scholars in different fields to express and evaluate trust [9, Ch.1]. Also, trust is a human nature feature, and it is even a complicated process that requires different levels of brain processing, especially reciprocal trust as explained in [10, pp.147-167], and the dynamic nature of trust can add up to all previous complications. All these findings show that trust is more than merely just numbers and applied math, so it has to be studied from other points of views as well, and not just by computer scientists.

Thus, we thought in our group work that a complex concept like that is better to be approached and studied from people in fields that deal more closely with issues related to human behaviors and interaction. These are the fields of social sciences, which include fields such as psychology, sociology, economic, business and social management, etc.

The importance of such multi-discipline study step is even mentioned in [11] during their evaluation of trust from different angles. Therefore, if we want our work as computer scientists to be more reliable and credible, we have to depend on such expert and knowledgeable people. Social scientists are the first to study concepts related to human behavior such as trust, so they are more suitable and better equipped to deal with this notion, and they have the real knowledge and tools to tackle similar issues in a way better than the ways of computer scientists. This is especially important when it comes to some controversial concepts such as the transitivity of trust where some scholars even in the same field (computer science) assume trust is transitive while others say not (this will be discussed more in details in the section of trust transitivity).

So far and to the best of my knowledge there has not been very much contribution to connect computer scientists' studies with social sciences studies when it comes to trust research. In other words, most of the studies and research about trust in the field of computer science are not backed up with evidence from other fields to support or dispute their findings.

Therefore, the objective of my thesis is to explore how trust is looked at from different points of view in social sciences fields, and this will help to make a bridge between computer science and other social sciences fields. In some points, this work will help to support some existing findings by computer scientists, and this will give these

findings more credibility. In other places, however, there will be some contradictions, and this will give us, computer scientists, some insights for future work and improvements. This is crucial because it is not the job of computer scientists to study trust, so they have to get the conclusions from people who know best about this matter (social scientists), and only then they can use the computers in order to automate the study of trust.

In sum, this paper will be such a collaborative view and multi-discipline study of trust in today's networks from different points of view. It aims to improve computer scientists' work when it comes to analyzing trust, especially the trust model in [1].

1.4 Thesis Organization

This thesis will be organized in the following manner: first, it starts with listing some of the related work that is similar to ours in chapter 2. Then it moves to chapter 3 that gives a brief overview about some trust definitions from different fields. After that, I proceed in chapter 4 to talk about the trust model proposed in [1] that I am depending on in my discussion. This model had been previously developed by the group I am working with now. I explain how modeling trust and managing it requires several points to be taken into consideration. This is coupled with explaining the metrics and principles used proposed there.

From this point on, the paper will be divided into three parts/chapters depending on the stages of processing trust, which, according to [12], can be categorized into:

1) Trust mapping/modeling.
2) Trust management.
3) Then the final stage of decision making.

According to [2], all these three stages should depend on **the context of trust**, so they may change depending on that specific context (or setting) in which trust is analyzed and studied.

The first step in processing trust which is modeling/mapping will be discussed in chapter 5. In this chapter, I list more in depth the factors that I found can be related to this stage, especially from social sciences points of view. These points are: trust being dependent on context/content, trust and timing including forgetting factor and other timing effects, trust and experience, trust and reciprocity. When some of these points are used in the discussed model, a connection will be made to compare the outcomes between the two different fields. At some times, small experiments will be done to support some findings. Other times, I will be giving some insight to what could have been done better or differently to get better results. I sometimes pin point to some drawbacks I found in the discussed model as well.

Chapter 6 will be devoted to talk about the next stage which is trust management. Here I will discuss trust transitivity and aggregation. I will list some papers and experiments that people in social sciences have done that are closely related to these two concepts. Most importantly, I try to provide some insights about the concept of transitivity from social scientists points of view.

In both previous chapters, I try to mention which points from what we dealt with in our work are supported by social scientists, and which ones are contradicted, or what can be done in the future in order to get better outcome.

The last part will be related to decision making stage which is discussed in chapter 7, and this part will talk about the role of reputation in building trust. Finally, I conclude the paper, and make some future work suggestions in chapter 8.

Before I proceed, however, I would like to clarify some points that may be a bit controversial along the way when reading this paper. During my study to these kinds of social sciences papers, I was trying to make a connection between their way of tackling some issues and our way. Sometimes, they may have used different words to express the same ideas that we, as computer scientists, express in formulas or in a more scientific way. My job was trying to read between the lines in a way that make the connection more clear. This will be clarified when needed. However, I just wanted to mention this point ahead of time, so when interested readers refer back to the original papers that contributed to this work, they do not get confused looking for the same words. Instead, it is an encouraging way to read between the lines and try to infer what is not explicitly stated. In my opinion, this is the best way to make the connection between different fields which are using different terminology sometimes to express the same matter.

CHAPTER 2. RELATED WORKS

As I stated earlier, there is not much work done to connect computer scientists' work with social scientists' work in the matter of trust management and mapping. Thus, I will mention some of the small contributions out there, even if they have a brief insight in their work about a connection between different fields. In addition, I will list some of the work in the field of computer science in general when it comes to trust models, managements and transitivity since all of our work basically depends on this. In fact, there are many interesting papers in the field of computer science in the form of surveys comparing and describing different trust models or the same concept of trust but in different settings and networks. For example, in [13] different definitions of trust were analyzed from different angles trying to explain how it can be managed in different settings and internet applications. Also, in [14], there is a thorough study about trust in social networks from different points of view, where different definitions and aspects of trust were discussed, in addition to focusing on some aspects of what they defined as social trust.

In [15], they try to analyze the concept of trust transitivity and come up with some principles and factors that go along with social psychology findings and some features of trust. They suppose that many different factors play a role in trust transitivity and all

these factors should be taken into consideration in order to build a successful transitivity outlines. Some of the factors they consider are the role of recommendation and how much similar users are in their preferences. This is in addition to the role of social intimacy between participants. Using all these factors as inputs and attributes in their proposed model in [15], they show how they get good results in their experiment in computing trust values along the transitive path.

In [11], they also try to study trust considering multiple fields. They mention how trust is defined differently by researchers in different disciplines such as economy, psychology and sociology. These differences may create some kind of conflict, yet make the concept richer in value [11]. This is in conjunction with a lot of overlapping in the concept of trust between all these fields [11]. The work in [11] also tried to investigate whether there is a common ground for trust between all these disciplines regarding the dynamic nature of trust, and what are the different ways to model it among them. At the end, they were hoping to create a clearer view of trust among different levels, firms, and organizations and study the way it is modeled. Several studies were cited in [11] in order to answer some questions related to trust and some of its concepts, how it is analyzed, its levels, its different forms, and the way it is viewed and tackled by different scholars.

Marsh's work in [16] is one of the best well-known in formalizing trust, and it is cited frequently. He approached the matter considering aspects and fields such as sociology, biology, and psychology as explained in [16]. This is in order to come up with a computational trust model explaining the relations between these different contexts in a formalized way. He used arithmetic formulas to represent trust, where he categorized it as being general, basic, or situational trust as showed in [16].

The model in [17] is based on experience, direct trust, and reputation; all of these factors are considered main factors in the mapping stage as I will show in the following sections. They also use recommendations on the way to come up with the final trust value, so the final decision to trust or not depend on a combination of all these factors as explained in [17].

Another work trying to gather information from different disciplines to analyze trust from many angles is in [18]. In [18], they argue that this is an important step since the concept of trust is manipulated differently among different researchers depending on their purposes. Their goal is to shed the light on this issue and come up with a base line that gives the concept more accurate use in different dimensions and levels, especially in the business field. They present trust in fields like economic, psychology, and philosophy.

In [19], they apply their experiment on Facebook data, specifically its wall posts trying to monitor/study the triads and the transitivity, which give an idea about the nature of interaction between users and the motives behind it. They identified many factors that influence the interaction between users including the effects of relationship's strength and bonding among these members as explained more in [19].

Many research in social and computer sciences fields have considered the importance of reputation in building trust. In [20] for example, the authors try to build a model considering the role of reputation, by introducing new ideas in their work to overcome some problems in previous models when it comes to depending on direct experience as a source of trust. They stated that the approach of experience reliance alone may not be the best one, and it may even introduce some kinds of errors in trust measurement, especially if the experience is not built for a long enough time to be

accurate. Therefore, in [20] they incorporate some kind of reputation information in their model trying to solve this problem which results in introducing what they called a certified reputation. This will help the other agents to evaluate their trusting decision more accurately according to [20].

Also, in [21] they take the role of reputation into consideration when designing their framework. This is done by giving the agents in the network the ability to dynamically participate in the process of trust. The agents themselves build a reputation table of trust values about their neighbors (through direct or indirect experience they had with them), where the negative behavior of a neighbor will affect the trust value in this table negatively, and this will be spread through the network in order to warn other agents from suspicious people [21]. According to [21] this way they can reduce suspicious behaviors in providing feedbacks, yet cannot eliminate all of it. This is because they merely depend on having a reasonable number of honest users that can overcome the untrustworthy ones, but again cannot eradicate them completely as stated in [21].

Other extensive work has been done by Josang, who mostly depend on subjective logic in his evaluation of trust like his work in [22]. The use of this subjective logic is what makes his work special because this takes into consideration the uncertainty that subjective concepts like trust hold in its meaning, in addition to considering the belief of individual users toward it [22]. In the same paper, they describe the difficulties they had in finding the right operator for a concept as subjective as transitivity, but they approached the matter with its uncertainty providing new insights over the pre-existing proposed models as they elaborated in [22].

In [7], it is another joint work between two fields: computer science and sociology, which was done in order to monitor the structure in a big network like Facebook providing some evidence on the progression that networks in general can do over time. This evolution of course includes many features related to network structure and properties, and one of them is transitivity. Facebook wall posts and randomly chosen triangles were main elements in the study in [7] enabling them to extract information about the studied network. Time is considered an important factor in [7] as well, so they use the information provided by their collected triangles at a specific time interval trying to predict the network status and properties at the next time intervals.

In [23], they also study the factors that affect people's trust in each other, and they show that some factors may even decrease the level of trust that a person feel toward another. Such factors include: some characteristics related to individuals' personalities, belonging to specific minorities group, some economic factors, and whether these people come from heterogeneous or homogeneous community [23]. All of these factors have effects on how people deal with trust information and handle it in different situations.

In [24], an experiment was conducted to observe how trust develops through different kind of mediums. Some of them promote more cooperation and collaborations than others. They studied face to face and video communication which proved to be both good compared to merely messaging or audio connections as shown in [24]. This study was done using game theory and social dilemma rules.

Another paper for the same researcher of [24] is in [25] where the experiment is to show how doing some actions to get to know your partner a bit before interacting with him online will raise the trust between both sides to be better than the case where there is

no such knowledge beforehand. Such activities can be done online and may include meeting online or messaging. The bottom line in [25] is that any (even simple) information obtained about the other side before starting the interaction, will help in paving the road for later trust with him online in a way similar to live meeting.

In [26], we encounter another joint work between artificial intelligence, philosophy, and cognitive psychology. Their work depends on using some experiments trying to prove some points related to trust dynamicity nature, and how it varies from time to time. Their study specifically targets the role of experience in trust (negative and positive ones).

Finally, there have been some studies including Twitter website as well. For example, in [27] they examine the content of some users' tweets using some special tools to see how the mood and attitude of the users and the network in general over time may affect and even help in making some predictions related to the field of stock market.

CHAPTER 3. TRUST DEFINITIONS

Trust study has been a very motivating topic to discuss by many scholars, so it has been studied in many areas including social and natural sciences fields [8]. In this section, I will briefly go over some of the different definitions and concepts of trust trying to show how diverse this concept is.

When it comes to defining trust, there is still no one unique formulation to contain all different meanings in a way that scholars from different fields agree on [9, Ch.1], [11]. Each investigator gives a different definition of trust depending on his area of focus and study, so it cannot be applied generally for other fields as well [9, p.7], [11]. This could result in insufficient definition of trust that does not take into account all different faces of it [9, p.7]. The definition of trust, however, should not be related just to one specific domain, but should be more accurate and thorough, one that should take into consideration all important features and characteristics of trust [9, Ch.1]. In [18], they mention the difficulty in coming up with such general common definition of trust given its complicated nature.

Due to all this confusion surrounding trust, they tried in [9] to come up with a model that generalizes the notion of trust without being dependent on a specific domain.

In order to do that, they depended a bit on the work of Castaldo in [28] where he used thorough and comprehensive techniques to study trust. Seventy two different

definitions of trust were taken from different fields and collected through the years in [28], and this study shows how mixed-up and vague the definition of trust has been in different fields [9, Ch.1]. According to [9, p.9], Castaldo's study reveals that the definitions of trust can be dependent on five classifications which are: the trustee, the construct of trust, actions or the behavior, the result or the expected outcome from the process, and finally there is the risk to be taken in the trust process.

In [9, p.10], they noted that trust is a conception with multiple layers in the sense that it has several meanings and definitions such as (trust is credibility, evaluation, confidence, expectation, decision, intention, sincerity, belief, dependence or reliance, attitude, and competence, etc.).

In spite of the different meanings of trust, there is some kind of settlement about the elements or factors that should be involved in the trust process among different fields such as psychology, sociology, and economy, and these two important factors are: taking risks and interdependence [11]. Taking risks should be combined with some knowledge and data about the person someone is going to deal with in the trusting process, so this information helps to reveal or gives some insight about the trustworthiness of this potential person to interact with [18], [29].

In addition to these factors being agreed on by most researchers, some other papers state that trust is also agreed on to be a belief, meaning that you have some faith in the person you are about to trust, and you expect this person to do the job you anticipate and expect from her/him [8].

In the field of marketing, trust has started to be recognized by its important role in sustaining good relationships and improving sale activities to be in a better shape [18].

To be uncertain about your trust decision, and to put yourself to be vulnerable in this process seem to be very important elements in studying trust on many different dimensions [18].

The difficulty in putting all pieces of trust puzzle together stems from the fact that trust is not the same in different context or situations, so it is different in different contexts [18].

In [30], they mainly focus on trust meaning as to anticipate some kind of behavior or action from the other person, and to believe that this action or behavior will happen. This true belief is what motivates the trustor to make himself vulnerable for that trusted partner. Two types of trust were proposed in [30] which are either trust in belief or trust in performance. This is done in the process of proposing a formal model to deal with some important questions about trust transitivity and semantics in general.

Another important definition in [31] can be summarized that a trust action manifests itself when a person encounters a situation that is not completely clear, and the consequences of following its path could be good or not good depending on the act of the trustee. However, he (the trustor) may choose to take the risk and follow the trusting route, or he may decline the whole trust process. It is also noted in [31] that the negative effects of following the wrong path may be very bad, so the trustor will be eager to take the right choice, and this definition mentioned in [16] as well.

There is also a well-known definition of trust in [32] that holds in its meaning that trust decision is kind on gambling in the sense that it is related to how the other partner will relate back to you in the future when you risk trusting them at the present without knowing or being able to expect the outcome ahead of time.

In [5], the researcher bases his work on two types of trust: the decision trust and the evaluation trust. The decision trust means how much one agent is ready to rely on and trust another hoping to fulfill its needs, and this decision is to trust in spite of the possible bad outcome [5, p.43]. The other type of trust is the evaluation trust which is probability that is subjective in nature, and it happens when a person Y evaluates how its partner Z is acting to achieve what is expected from her/him [5, p.43].

There have also been some surveys done to come up with some features related to trust and distrust like: trust is a subjective concept because each agent may evaluate differently the same person or the same object [5, p.12], [33]. Trust is directed, so for example Y may trust Z to be a good teacher, but Z may not trust Y to be a very well-informed student [5, p.12], [33].

Marsh in [16] has done some of the most thorough work in studying and defining trust and come up with a formal model describing it as stated in [34]. He was trying to collect and study the concept of trust from different points of view as stated in [34]. Thus, some of his work depends and cite researchers from different fields and area of interest. For example, Marsh discussed some of the work presented by Luhman (such as the one in [29]), whose approach is sociological in nature according to Marsh in [16]. Other parts of his work also discussed the work of the researcher (Deutsch) who focuses on studying trust from a psychological point of view, according to Marsh in [16], among other cited researchers. Marsh did also discuss the subjective nature of trust referring to an important paper in [35], that discusses how trust is a subjective concept because different people may have different opinions and trusting choices about the same matter, which results in

multiple definitions and opinions even about the same issue. This is what makes this concept a very complex notion to study, analyze, and even to simply define [16], [35].

Marsh also in [16] discussed the work of Deutsch which was presented in [36], where Deutsch proposed about 19 trust related hypotheses that express different situation, and he tests them using some psychological experiments. Marsh also in his work in [16] categorized trust into three parts which are: basic trust, situational trust, and general trust.

Other two definitions are offered in [3]: one is the reliability trust that is inspired by the work of Gambetta in [37], and the second definition is for trust as a decision.

Another well-known and cited definition is the one mentioned by Dasgupta in [38], which also focuses on trust as expectancy of good deeds or bad deeds from people, and acting up depending on this expectation before knowing the reaction of the second interacting party.

Even when some researchers were doing some experiments to study the process of trust and how it is built or destructed, they distinguished between the different meanings of trust trying to explain which one they depend on in their study. This shows the variety in trust definition and the different ways it is tackled. For example, in [39] they revealed that the results of their experiments depend of trust as attitude and not trust as behavior. This is because they just interviewed the actors and asked them questions in order to evaluate their trusting options and plot the results, and this implies their attitude about trust. However, researchers did not monitor the real behavior of these actors in the real life about similar situations, and how this attitude can be interpreted and transferred into real behavior in real life, and this is why it is not considered trust as behavior [39].

These above mentioned definitions are just like a drop of water in the ocean. The list could go on and on, but I just wanted to mention some of most used definitions in the literature in a way that gives an idea about how this concept is approached differently from different disciplines; sometimes even from people in the same disciplines but with different interest.

CHAPTER 4. THE DISCUSSED MODEL

The model I will depend on in my study is the one proposed in [1], which had been developed by a team work at my school with my advisor. Joining this team, my overall goal was to improve the way this (already proposed by them) model works, and the way they map trust data, use formulas, and manage trust from the perception of social scientists (depending on their findings).

There are many proposed trust models in the field of computer science, but what is special about this model is its use of the measurement theory in calculation, and it is because this theory is similar to the way trust process works in human being [1]. According to [1], in both cases someone can have an initial measured value (which is represented by the initial trust impression in our case) that can be improved later on by follow up measurements using different tools to decrease the error (trust can be improved through repeated interaction with the same person in our case as well).

Depending on this kind of similarities, two trust metrics were proposed in this model, which are the impression (m) and the confidence (c). The impression represents the initial trust measurements that a person Y, for example, makes toward another person Z to evaluate how much he is trustworthy [1]. The next metric: confidence (c) is similar to the error in measurement theory because it represents how much Y, for example is sure about the trust impression he has just made toward Z [1]. Of course, human can do more

than one evaluation in order to be more sure and certain (confident) about their trusting decision about a specific person, and this is similar to repeating the measurement in order to decrease the error in the measurement theory as stated in [1].

The model was tested using a dataset taken from another study for Epinions website, which consists of 405,154 different individual users who have some kind of shared reviews or ratings between each other to some degree.

The same model is discussed again in [2], but they also tried to use different dataset in the evaluation which is a dataset collected from Twitter website. The data there was gathered from a public group related to stock market, where the IDs of users following this group were first acquired, and then these ID's were used to collect their corresponding information, and most importantly their tweets using Twitter API tools and twitter4J library as explained in [2].

In addition to the metrics of impression and confidence, the proposed framework depends on error propagation theory in the computation, along with the use of transitivity and aggregation concepts as means of trust propagation, and all these combined will help in the process of coming up with the corresponding arithmetic formulas [1].

They express the concept of transitivity using the multiplication operator, and I will justify the use of such operator from social scientists point of view later on in section 5.3.1. Thus, if A trusts B, and B trust C, then the indirect assessment of C's trust level, made by A, and through B recommendations will most likely end up with the results of A trusting C, which means trust is transitive [1].

Two principals were proposed in [1] to express how transitivity works in a way that could be psychological based. These proposed principals can be summarized that

transitivity does not increase confidence or impression along the transitive path, because the original, direct impression or confidence is most likely stronger than the indirect one.

Since in real life, trust information may come from more than one source, trust aggregation concept was also discussed in [1], so both the impression and error have to be aggregated depending on the rules of error propagation and measurement theory.

Along the way, different paths in the aggregation process will be assigned different weights depending on the confidence level of that specific path as shown in [1], and this will also be discussed more in depth when talking about aggregation.

Similarly to transitivity, two principals have been proposed in [1] related to the aggregation process, and in chapter 6, I will go through both of them and try to support their validity from social scientists perspective.

The way trust is mapped in [1] for Epinions is a little bit different than mapping in Twitter in [2]. This is because the way of interaction between users differs between Epinions and Twitter, and in fact it is more complicated in Twitter.

In Epinions, the process of mapping trust is kind of evident since users express their trust using some kind of ratings, reviews, and stars [1]; in Twitter, however, it is not that straight forward case. That is why in [2], they have to depend on other measures and signs to help them in the mapping process, so they used some kind of sentiment analysis tool as the one in [40] in order to evaluate the content of each tweet. This way they can judge whether this tweet is considered positive or negative in its meaning.

After this step, they convert the value resulted from analyzing the sentiment to a value between zero and one in order to represent the trust impression as it is shown in [2].

As I said earlier, my job is to enhance the way this model works, so I will be referring to this model frequently. In order to make it easy and clear on the readers, I will refer to this model by saying (the discussed model), and I will try to pin point to the dataset used in the study (whether taken from Epinions or Twitter). I just wanted to note this in here so it becomes easier on interested readers to navigate through this thesis easily and be able to point accurately to what I am referring to.

Now that I have covered the basics of my thesis and the discussed model, the paper, as mentioned in the introduction, will be split into three chapters according to the phases of processing trust mentioned earlier in [12]. The first phase that will be discussed in the following chapter is the stage of trust modeling or mapping.

CHAPTER 5. TRUST MAPPING

The first and most important stage in studying trust and coming up with a model to represent it is the stage of mapping, so what does mapping mean?

According to [2] trust mapping or modeling means using the data and information available in hands (through the website or network we are studying) as a base trying to come up with metrics that can be formulated to represent trust. Of course, the more data available to use, the better mapping we get. This is because more factors used in the mapping process provide a better picture about how trust is expressed in that specific situation. All these information is to be used later in the stage of trust management [2]. Some examples include: reviews in Epinions, stars from Amazon, Facebook wall posts, Facebook like/dislike, and tweets in Twitter [2].

Given the importance of this step, I tried to summarize which information may be useful to be taken into account in the trust mapping stage in order to get a better outcome and more accurate mapping, especially from social scientists' points of view. These points will be discussed separately throughout the paper, and include:

- Trust and content/ context.
- Trust and timing.
- Trust and experience.
- Trust and reciprocity.

5.1 Trust and Content/ Context

In multi-disciplines study of trust found in [9, p.29], it is argued that trust depends on the content or on the context. Thus, in analyzing the main elements of trust they include the context of trust as main element in the entire process in addition to the trustor and trustee [9, p.36]. In other words, person A trusts another person B to do a specific task or to achieve a specific goal, and this is just in a specific context [9, p.36]. Sometimes the same task may exist with the same trustee, but in a different context or settings which change the trust outlook that this trustor will hold toward this trustee as shown in [9, pp.83-85].

Moreover, they showed in [9, p.150] that trust is related to what is called causal attributions, so A's inability to achieve the task expected from her does not always results in less trust toward her from B and the reverse is also true, so A 'success in her task does not mean more trust from B toward her because it all depends on whether this kind of effects is internal, external, stable, or occasional. In their example, A may trust B more even if B did not get the job done at the end, but A witnessed that B at least did a lot of hard work and that is sufficient from A's perspective to trust B again in the future; In this case, maybe there were some external occasional factors that prevented B from having the job done, so factors not related to B specifically; this is why it did not affect A's trust in B as explained in [9].

However, this kind of effects related to causal attributions is not easy to be captured when modeling trust, so for the time being it was not taken into consideration in our work. We may get some kind of surprising results when an agent seems to trust

another in one way and not another, or when an agent seems not to trust another agent even when the latter has done the work expected from her. Still, we cannot capture this kind of effects, especially in the online world when you do not have a clear picture of the people behind the screens, and the way they perceive and approach each other. Also, their decision could have been affected by some kind of knowledge that is hard to be captured when trying to map trust, since we usually look at the most obvious information or in other words, the information available to us in hands.

Now, we talk about the content issue that comes to mind, especially when talking about transitivity, so if A trust B, and B trust C, does that mean A will trust C?

According to [9, Ch.6], in the psychology field this is not always the case because trust transitivity does not simply depend just on the trustor and trustee, but it also depends on the content of trust in addition to the task/ competence on which the trust is built (what exactly is being transferred from one side to another). This mean that X trust Y to be competent enough and in a specific domain, so A can make her suggestion depending on this specific domain as stated in [41] as well. Similarly to the example stated in [9, p.171] and [41], I would like to illustrate: so if A trusts B on a ask t like as a computer engineer, and B trust C as a computer technician, so A is more likely to trust C as well because A trust B's judgment about choosing his colleagues in the same field since he is also competent in that matter, so A is sure enough about B 'competence in this domain that he can recommend someone else to be trusted as well. On the other hand, if A knows that B is not good enough in real-estate market and that B trust C in that field, so then A is less likely to trust C for that matter because A does not trust B's judgment or competence in this area even though A trust B in another area in which B is expert (as it seems to A).

This may also mean that A should consider B as influential person in his domain in order to adopt his point of view and trust C like him [41]. In other words, the discussion between all these parties should revolve about the same matter or issue (which means the same kind of content).

5.1.1 Discussion

Considering these points mentioned above, I wanted to reflect that on the discussed model. In other words, I wanted to see whether the relation between trust and content/context was taken into consideration in the mapping stage for Epinions or Twitter.

I think that this point was taken into account partially when collecting data from Twitter. This is because the data collection was done from the same group in Twitter which is one related to stock market as explained in [2]. I think that this can, to some degree, guarantees that most of the discussions taking place are about the same issue, and that trust process revolves about the same matter, so hopefully the tweets are kind of related to the same or at least to similar topics.

This can help to some degree in capturing the relation between trust and content because evaluating the tweets as a measure for trust degree between users will be easier assuming that they are all related to the same topic. Thus, we have the same environment which is the online world of people in the same group (same context), and we also have people (who are hopefully) competent in this domain, so they can be trusted in making suggestion. The competence also can be captured to some degree because influential people should be well-known in this group, so their suggestion can be trusted as well.

Having said that, it is assumed that when people in this group are exchanging tweets, it is somehow related to the same matter, so analyzing the content of tweets in order to deduce the trust level is considered to be content based (content related trust). However, I said earlier that this is captured partially or “to some degree” because in the online world we cannot guarantee that this is the case all the time, and we do not have control over the exchanged tweets or their content, but at least this point was taken into consideration when collecting the data.

However, in Epinions dataset in [1], this point was not taken into consideration because first of all the data used in their experiment was derived from a data collected for another study, so it was a random snapshot. In other words, the snapshot has different users evaluating different kinds of reviews which are written for different kinds of products, so there is no concentration on a specific matter in this snapshot.

Also, the formation of trust triangles there was kind of arbitrary. To illustrate, in Epinions, the way it works is that some people go and write their opinion or review about some products, and others go there and read their reviews and evaluate it by giving starts from one to five [1]. On the process of coming up with trust triangles and users who have direct or indirect links between each other (to have a link of trust is to have at least one shared rating [1]), the content of the review is not taken into consideration because choosing the triangles was random. So for example, in a triangle ABC, A may have evaluated B for some kind of review about a product (p), and B evaluated C for something else, and A evaluated C for completely different third thing. We may get some similarity, but it would be merely by chance. This is because the data was not collected targeting specific group of people with specific interests, but it was just general data

about people who gave their evaluations of others' reviews. Even when trying to form triads to study transitivity, the process was random, so there is no guarantee that the nodes in a specific triangle are all about evaluation to the same product or reviews. Thus, the content was not taken into consideration in Epinions.

This gives some motivation to do more work on Epinions data set in the future by using some kind of filtering considering the same kind of content, and comparing the results with the recent ones we have now hoping to find better outcomes. Doing this step may help to come up with a conclusion that is more in line with what social scientists state about the relation between trust and content. In my opinion this step will have a big effect on trust mapping and on the accuracy of the results in general.

5.2 Trust and Timing

Time plays an important role in a concept as dynamic as trust [41]. According to [41], the dynamic nature of trust comes from its changing nature over time, in addition to being related to the history and experience between the two interacting parties (direct or indirect experience).

Generally speaking, more time spent interacting with a person means more experience and information about him, so the level of trust about him will change over time. However, when it comes to social scientists, there are more complicated cases related to timing than this simple concept.

In the following sub-sections, I have categorized three cases where I figured time can be related to trust and can alter its outcome according to social scientists experiments.

5.2.1 Trust is Learnt over Time (Trust Dynamicity)

In [39], their whole study focuses on the effects of timing on trust, and how people learn to trust or not to trust over time. Their argument lies in the learning process that people go through over time toward their decision to trust/distrust others around them. They argue that this process depends on many factors such as the direct information a person obtain about a partner with whom he is directly interacting, or from others' opinions when they give their judgments when they are asked about a person.

The experiment in [39] was held in a dialysis unit in a Dutch hospital and lasted for one year during which measurements were taken every three months to compare how trust relations are evolving and changing over time between the participants in real life.

Some variables were used in [39] to express the whole trust process such as: a variable to represent the trust tie between 2 participants at different times, another one to represent the frequency of interaction, and some other factors to weigh differently the information received from different third parties. They assumed that by using the information available at previous time measurement they will be able to predict the tie and trust at a present time (t), and this information can be obtained either through direct experience of third party effects.

Since trust can be learnt through time (this is what this paper in [39] focuses on), users' recent trust in each other at time (t) is strongly affected by their trust in each other at time (t-1), so a positive/negative experience at time (t-1) is more likely to encourage/discourage trust at time (t) according to [39].

Studying the relation through different points of time (different measurements), there was some changes in the relations and ties between people over time where more than 50% of bonds changed over time even if it is just a small change as shown in [39].

This experiment is a simple way to shed the light about the effects of timing on the trusting process, in addition to the dynamicity of trust and its changing nature over the course of time between people interacting directly or indirectly.

In fact, this kind of result motivates us to focus more about studying the dynamicity of trust instead of just focusing on a static snapshot in the network. Most computer scientists focus mostly on studying static snapshots of the network, which deprives the trust from one of its most important features which is dynamicity. Thus, focusing on studying dynamic snapshots in our data is one of my most crucial suggestions for improvement and enhancement in our mapping stage.

5.2.2 Forgetting Factor

During the process of modeling trust for Twitter dataset in [2], the concept of forgetting factor was incorporated in the mapping stage. It means that by the time, users tend to forget their past experiences (or the effects of these experiences fade away with time) with their partner, and they tend to focus more on the most recent one which becomes the experience that matters most for them, so it has the highest impact in their subsequent trusting decisions as argued in [2].

In the field of social sciences, I found that they use a different way or different naming for the same concept of forgetting factor, but this is done in a way that convey the same idea.

Through these social scientists simple experiments with people, I have found that they somehow support the presence of the forgetting factor, and they include this kind of effects in their study.

Before moving to fields other than computer science, it is feasible to mention that some other computer scientists have given the idea of forgetting factor a bit of attention through their studies even if it is just kind of brief mention.

One example is found in [42] where they discuss the necessary elements for trust topology analysis and one of the elements mentioned as an important tool in this process is the time factor. They think that this is important because it provides the user with information about the most recent trust experience he had with another person, so he can depend on this info in order to evaluate his coming trust options [42]. I think that this indirectly point to the concept of forgetting factor.

Also, in [43, p.54] which is a joint study between different fields, they mention that the latest encountered experiences seem to be more significant than previous ones, so they give the old experiences kind of discount to express their decreased effects on making subsequent trust decision. They think that the most recent ones weigh more because they have better influence on making subsequent decisions than the old experiences, and this kind of effects was applied in their experiments in studying trust.

In [44], from the field of sociology, they ran a simple experiment questioning people and collecting their points of view about trust issues while they monitored their informal interactions with others. Their goal is to show how informal social bonds and continuous interaction with others increases the general level of trust in people toward each other, and they proved that through their work. They concluded that this heightening

in the general trust level help people to keep trusting each other even if they had some bad negative, and undesirable experiences in the past, so there is a chance that trust can be restored again as argued in [44]. I think this also means that what matters most is the recent value of trust and this implicitly represents the effects of forgetting factor.

Another paper in [26] has researchers from three different fields: artificial intelligent, cognitive psychology, and philosophy. They showed through a small experiment that the most recent experiences are more likely to be the focus and have more weight in the trusting decision than the ones happened a while ago. They used some experimental tools to show how trust changes from time to time depending on the kind of experience encountered (whether it is bad or good experience). The experiment in [26] simply depends on four groups of participants reading 2 sets of 10 stories (five stories about bad experiences that are assumed to decrease trust and five about good experiences that are assumed to increase trust). The trick is with the order these stories were given to the participants, where each group was given a different set of stories with a different order than the other groups in a way alternating between the good ones and the bad ones. They tried to control for the effects of such alternating action and balance the way the stories handed out to the participants because the goal is to monitor the impact that the changes in these stories order will make on the participants' trust attitude for next encountered experiences as resulted in [26]. The order of the stories makes a lot of difference because sometimes recent good experience may make up for the previous bad ones and vice versa. After that, the participants were given some questionnaires to answer in order to evaluate what they think, and the results were compared with another research done to study the dynamic of trust that can be found in [45].

I think that the results in [26] are somehow supportive for the forgetting factors and its presence. To illustrate, it has been showed in [26] that the group who was handed positive stories last had mostly positive trust attitude at the end of the experiment toward the object/subject in the story in spite of reading negative stories about the same object/subject at the beginning, so the positive stories (when read last) were able, to some degree, to override the effects of the negative ones read first. At the same time, they showed how the group who was handed positive stories first and the negative last mostly ended up with a negative attitude and less trust level at the end of the experiment. I think this means that after facing some recent bad experience, the effects of that will overweigh the effects of the old positive ones, and this result in negative trust. In my opinion this means that participants tend to focus more on their most recent experience in order to finalize their trust decision, which is similar to how the concept of forgetting factor actually works.

5.2.2.1 Discussion and Experiment

So considering the importance of this concept from social scientists points of view, the idea of forgetting factor was mostly taken into consideration in the mapping stage in Twitter in [2] as I mentioned earlier, where firstly after collecting the data they focused just on studying the tweets posted in 2013 and not before considering these ones in 2013 to have more importance in the evaluation process (since they are more recent). Secondly, even the collected tweets of 2013 were grouped into monthly windows, so each window has the tweets took place in that specific month [2]. They consider the most recent experience to be represented by the last month of collecting the data (which was the

month of October 2013 in [2] for example), so all tweets that were posted in that month were given the highest weight and their confidence value was not discounted when aggregating the final results. However, the confidence of tweets posted in the months before were discounted by the value of Forgetting factor (set to 0.9 first and then decreased for each previous month, and you can refer to [2] for the detailed technique). This is to represent the idea that as they are going back in time, the effects of the old experiences are fading and what matter most is the most recent one.

The model was tested to see how well it can predict transitive trust between users in Twitter dataset comparing two cases (with or without forgetting factor in the mapping stage).

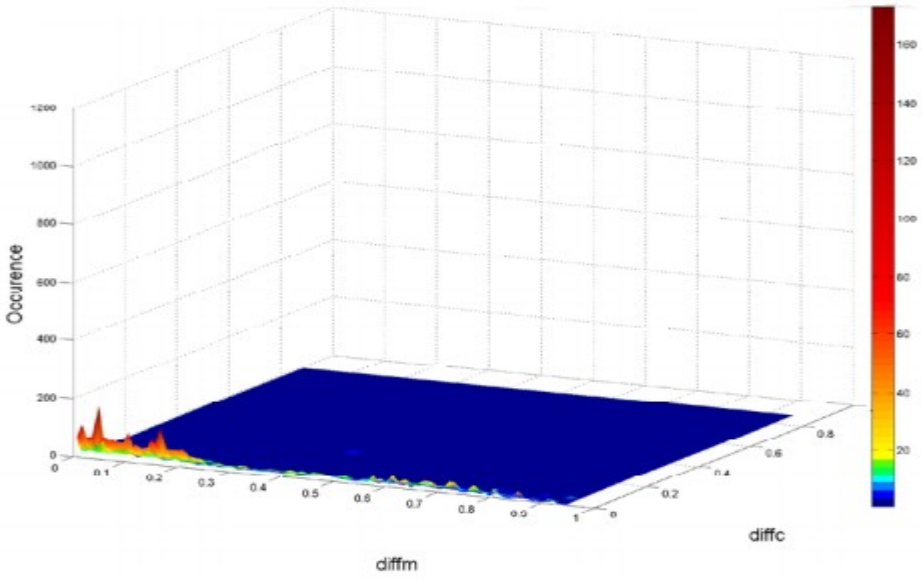

Figure 1. Twitter without forgetting factor

We notice from Fig. 1 above that without using forgetting factor, there is a low concentration of triangles or points in the area close to zero which is the area with small errors (Diffm and Diffc are small). This means that the frequency of times where the model predicted indirect trust accurately was not very high when forgetting factor was not considered in the mapping stage.

Diffm and Diffc are used in [1] to measure the error in prediction made by the model, where Diffm represents the difference between the impression that the model calculates and the impression that the user express himself, and the same applies for Diffc but for the confidence [1]. Of course, the smaller Diffm and Diffc, the better the model was able to predict indirect trust between users. We compare Diffm, Diffc for both cases:

With forgetting factor the error: Avg (Diffm) =0.2508, Avg (Diffc) =0.0963; without forgetting factor the error is: Avg (Diffm) =0.2905, Avg (Diffc) =0.0980.

Comparing Diffm and Diffc in both cases we notice that we have slightly better results (smaller values=less error in prediction) when applying forgetting factor compared to the time when forgetting factor was not applied. This may be related to the fact that forgetting factor effects are real in the network, and people in real life depend on this kind of effects in order to make their trust decision, so maybe that is why the discussed model performed better when this factor was considered in the mapping stage.

In our group work, we wanted to do more manipulation with the experiment related to forgetting factor, but we wanted to first get the insight from what social scientists have to offer in this area.

Through my search about this matter, I think that most of the time social scientists studies failed to provide us with some information needed for further support.

For example, as far as I read, there is no data or information to reveal the exact time window or threshold that people in general depend on when they want to evaluate their recent experiences that matter most. As far as I found, there is no quantification for the concept of time. In other words, what would be the threshold of forgetting factor; do people care most about experiences from last month or last week or just last day? In [2], they just consider the most recent experience to be represented by the last month, but it could be any number.

Also, it would be useful to know how we should weigh experiences from different periods of time. In other words, do experiences from last day get higher weight or importance than the ones from 2 days ago, or they should be the same? Do experiences from last month have the same importance as experiences from last 2 weeks? Do recent experiences have higher confidence and how much higher should that be? And if this is the case, how should we weigh or discount these different experiences at different times. All these questions are to be answered by sociologists and psychologists in order to give us insight in our work. Studies like these could have given us a base line about how to manage and tackle our data. This is very important when mapping trust because when this information is accurate in this stage, it helps in capturing trust in a better way.

This information, however, may be kind of tricky and subjective that differs from one person to another, and form one situation to another. Even in [26], they have found different results when comparing how many bad experiences were enough to turn down the level of trust, and how many good experiences were adequate to turn the level up in different settings. In other words, there was no definite answer to how much time and frequency of experience is needed to fade away the effects of the old past experiences.

Thus when findings some answers from social scientists, it will be a great motive to play with the above experiment again and compare different results, so we can get more thorough study, and hopefully better results compared to what we have now.

5.2.3 Timely Response Effects on Trust

Another good point to be taken into consideration in mapping trust is timely response or how fast someone responds to you. For example, many people in real life evaluate the trustworthiness of their friends or even online strangers by the time they take to respond to messages, some online posts, or emails, etc. as stated in [46].

In the field of psychology, there is a theory named fundamental attribution errors, which simply state that people judge others' personality when something wrong happens instead of blaming external environmental factors as explained in [46]. However, people tend to blame the external situation to explain their own behavior when something goes wrong [46]. This is because people know the whole conditions surrounding their own situations and what is happening in their environment, so they can easily place the excuse on that, but they are not clear and they do not have enough information about other's situations, so they tend to blame their personalities to help them find excuses for others behavior [46]. For example, if you are late for a gathering, person A tends to jump to a conclusion and start accusing you of being not punctual, irresponsible, etc. instead of giving excuses for your situation that something external not related to your personality may have happened that made you late. However, if the same person A is late himself, he tries to find other external factors that contributed to his situation such as the traffic, the weather, etc.

This theory is very good at explaining why timely responsiveness in social media is very important in increasing the level of trust and save someone from being called untrustworthy, according to Judy Olson, the researcher who have many studies in such fields and who was interviewed by the author in [46] and reported all these findings.

Thus, they insist in [46] on the importance of keeping up with answering messages fast on Facebook, Twitter, or any other media even if you do not have time for a long response. They think that even a brief reply shows the other person that you care enough to respond, and that you are, in turn, trustworthy.

Even if someone has some special circumstances, this does not give him any excuse for being late in replying in social media since the people on the other side are not able to see or judge these circumstances, so they are fast to jump to conclusions about untrustworthiness of that particular person as discussed in [46].

There is another study reported in [47] that shows that the responsiveness of the person who created the post or blog was one among the reasons why people may trust some blogs or contents more than others, which bring us back again to the importance of timely response in trust relationship.

5.2.3.1 Discussion and Suggestions

Till now the idea of timely response and its relation to trust has not been studied at all in our work. Due to the importance of this idea, I think it will be sufficient to incorporate this idea in studying specifically Twitter. Twitter mostly depends on exchanging tweets between users. It would be interesting to monitor if timely response for tweets between users has any effects on the final level of trust between them.

However, a study like this need more tools to be implemented because as in the forgetting factor, we are dealing with subjective concept here. For example, 3 days delay in response may look ok for some people, but may induce distrust for others. Part of it, in my opinion, depends on the kind of relation between the two interacting parties, where people may deal differently with situations related to different kind of friends or to different kinds of relations.

5.3 Trust and Experience

Many studies have focused on the role that experience plays in the trust process, where it can either increase the trust or decrease it depending on the type of experience encountered. Thus, experience is another factor to be taken into account when mapping trust because it will give us a sense on why some users are acting the way they do.

In [9, p.150] they argue how the direct experience is widely viewed as being one of the major and primary sources to build trust. In general, good successful experience increases trust and the bad ones decrease it [26].

However, cases like these do not always happen to be straight forward since it can be related to what I mentioned earlier in chapter 3 (causal attributions), so good experience may not always result in better trust and bad experience may not always result in less trust because it all depends on how the trustor sees and evaluates the factors (internal, external, stable, occasional) surrounding the trustee as shown in [9, p.150].

In [26], the experiment I explained previously when talking about forgetting factor, they also focused on the dynamicity of trust and how experience plays an important role in it over time. Their findings show how good experience over time

increases trust or it may stay the same but does not become less, and how bad experiences have mostly negative effects on the outcome of trust level. Researchers even found that sometimes bad experiences and negative behaviors have stronger effects that contribute to destroying trust more easily than the way the good ones build it [26]. The relation between trust and experience is also mentioned in [48] when experimenting with a group of managers, where they also found that relationships that have been built for a long period of time are more likely to be stronger and to have higher levels of trust between the members compared to short term relations. This again shows the role of experience in trust because a long time relationship implies more experience, and in turn better trust.

Another paper in the field of sociology studying the effects of time and the process of trust learning between the members is in [39], (explained earlier in section 5.2.1). Many questions were asked to the staff of this dialysis unit in [39] to help in assessing the level of trust or distrust between them, and these answers were decoded in a way that helps in obtaining results. The measurement is for the trust amount and how it changes during the time of this study, what the effects of that are, and what are the reasons behind this change. Their results in [39] strongly support the effects of experience and timing on trust because monitoring the participants gave them an idea how they prefer depending on their own experience in evaluating their trust judgment, or they turn to trusted third parties to provide them with this information in case they had no clue. Building up on this information from either direct or indirect experience, trust level showed to change from time to time in [39].

5.3.1 Discussion and Suggestions

So how can we reflect the role of experience in the mapping stage of the discussed model? Was the role of experience taken into consideration there?

When talking about the discussed model in chapter 4, I mentioned that in dealing with transitivity formulas, they used the multiplication operator to express transitivity that: if A trust B and B trust C, so the indirect trust impression from A to C through B will result from multiplying the values of impression from (A to B) by the impression value from (B to C) [1]. From the talks about trust and experience above, it seems that many researchers in different fields focus on the role of direct experience to be one of the essential sources of making trust decisions as argued in [9, p.150]. Thus, direct experience should have a higher weight when people are making trust judgment than the indirect one. Thus, the impression value from A to C through B will be discounted by using multiplication of the two direct trust impression values (since the value of trust impression in the discussed model is less than one, so multiplying two numbers which are both less than one will result in a value less than both of them). Thus, this multiplication will be a pointer that the direct experience generated by direct interaction between B and C, in our example, will always have a stronger impact on trust decision than the indirect one generated between A and C by the transitive path. In fact, this idea was discussed in [1] when building their transitivity principles. Thus, I think the use of multiplication operator in expressing transitivity is justified from social sciences points of view.

The same was done when aggregating multiple paths in [1], so paths which were found to have more interaction between users, and in turn better experience, were

assigned higher confidence on the aggregation path. This expresses the idea that the better you know the person (from repeated experience and interaction), the more confident you are about your opinion about him/her, so paths like these will have a higher weight and impact on making trust decisions compared to other less important trust routes (the ones with low confidence) [1].

However, I have to disagree with this approach to some degree. I agree that when evaluating trust options we have to take all paths into consideration, but we have to be very cautious when there is a direct experience, where people may tend to depend mainly on that. Thus, I think this point should be looked at again so when there is a direct experience involved, we have to think more closely about aggregation effects on the final trust level between two users. However, since the data we are studying is just a snapshot of the network, it is harder to capture the effects of experience evolving over time. Therefore, my suggestion for more accurate results is to do some kind of longitudinal study about the network we are analyzing, where a new snapshot of the network is taken at least every few months over a long period of time so we can use these different snapshots to monitor the changes in trust levels using time and experience as main factors.

5.4 Trust and Reciprocity

Reciprocity is another interesting idea related to trust and one that should be incorporated in the mapping stage. It simply means that there is some kind of relation between A and B where (A) helps/trusts/cooperates with B and B will return the favor to A in the same manner. Reciprocity plays a vital role in building trust as shown in [10], and many social scientists study this relation in their papers as I will be showing in this

section now. They mostly focus on the factors that should be present in order for reciprocity to prosper or diminish, and this in turn affects the level of trust between users.

We can look at this matter from two different angles: either reciprocity increases trust because it increases experiences between the two reciprocating sides, or trust increases reciprocity because you reciprocate expressing how much you trust that person, as in [10] where (throughout the book sections) they studied different scenarios showing how the two concepts work together in different cases. In any way, we can still say there is a positive relation between these two concepts. According to [10, pp.147-167], reciprocity is a complex behavior that can be studied at different levels in human brain: the behavioral level, the strategic level, the evolutionary level and the neural level. Building on these, they study how reciprocity is established between two people, and suggest many theories and mechanisms behind that process.

In [49], researchers use the concept of investment game in their study to monitor reciprocity, which is a very essential game in showing the relation between trust and reciprocity. According to [49], the investment game simply works as follow: participants are separated in two rooms then paired randomly (one from each room) to play together; the senders are given some amount of money, and then they choose either to send some to the receivers in the other room (whom they may not know) or not to send any. In case they send some money, this amount will be tripled and sent to the counterpart receiver, who then has the choice to send some back or not at all.

A study was conducted in [49] that found how most participants had a tendency to cooperate by sending some money to their counterparts even when there was no prior history or knowledge between them. That was explained in [49] as accepting to lose some

money by the senders in order to gain trust back from the receivers in the other room hoping that this will result in more cooperation and reciprocity from these receivers (expressed by sending money back again). In fact, this was the case with some receivers who sent back even greater amount of money, while the rest were selfish and sent nothing.

When participants in [49] were given some backup information about their counterparts, it (in most cases) increased the level of reciprocity between both sides in addition to the amount of money sent and received. However, if the information provided about the partner history is negative, it weakens reciprocity and in turn, trust. This is because participants were more inclined to act in a good way with cooperative partner while punishing the bad or non-cooperative ones by not cooperating back with them and not sending them any money.

I think this paper shows us how trust and reciprocity are related, and that they enhance each other in one way or another; also, this reciprocity is affected by the information people have about their partner' s past history, and whether it is good or bad as shown in [49].

In another paper in the field of business and management, researchers talk about the relation between trust, cooperation, and the strength of the relationship between participants and it can be found in [4]. Researchers here used the same concept of investment game used in [49], but they applied it on some data collected from Facebook using a special application, which assign friends with different strength of relation randomly to play together. The strength of the relation between matched up friends in [4] is measured by taking three factors into consideration: the number of times these two people are appearing in tagged photos together, the number of times they are sharing wall

posts, and the number of mutual friends between them. They found that the first two factors had positive influence on the cooperation levels between the friends, so they can be used to measure the relation strength, while having mutual friends did not seem to affect the level of reciprocity and even worse it sometimes contributed to negative results, so it is not a good pointer to true strong relationship as it is shown in [4].

The excuse that researchers in [4] found for this is that in Facebook adding friends is a very easy task and many people do it just for the sake of adding friends without true relation, while being in common photos or exchanging posts have something to do with real friends in real life. This study sheds the light on how reciprocity is affected by the strength of relationship where the stronger the relation, the better reciprocity we get [4].

I think that their findings in this study is very crucial for us as computer scientists because it warns us not to rely much on the metric of mutual friends in evaluating trust levels and reciprocity motives between people. This is especially true when evaluating mutual friends' effects in economical settings where money is involved, as it was the case in the study done in [4] using investment game concepts.

In [50], they also mention the presence of two types of reciprocity which are direct and indirect reciprocity. According to [50], the direct one refers to the mutual reciprocity/trust relation where A reciprocates with B and B reciprocates back, while the indirect one is when A reciprocates with B but B reciprocates with someone else instead and not necessarily back with A, or when A reciprocates with B and someone else reciprocate with A. It is mentioned in [50] how this kind of indirect reciprocity is known by its essential role in enhancing reputation of the person performing this kind of action.

The concept of indirect reciprocity is important because it proves that human being do not necessarily act just out of self-interest and selfishness [50]. This demonstrates that cooperation stems from being a part of human nature, so people do not act in cooperative way just waiting for others to return the favor to them as argued in [50].

I think that this finding is a very important finding for us as computer scientists because it inspires us to give more weight through our study to the role that reciprocity plays in the way trust is built and processed between cooperating users.

Game theory is another important tool that helps in studying the relation between trust and cooperation [10, p.210], and prisoner dilemma is a very well-known game studied and used to illustrate the role of communication in trust and cooperation, as illustrated in [10, p.210].

Prisoner dilemma simply goes like this: two guilty people of the same group are arrested and put in separate prisons with no ability to communicate with each other, but they do not have the final charge yet on how much they will spend in prison; this decision will be made depending on the action both prisoner will take independently by either confessing the crime or remaining silent [10, pp.210-213], [51], [52].

There can be four scenarios to how the outcome of both prisoners changes depending on how each individual acts separately, so for example:

1) If both prisoners admit against each other, both could serve 5 years in prison, for example [52].
2) If A confesses against his partner B and B did not confess against A, then A will go out of prison, and B could spend 10 years in prison [52].

3) If B confesses against his partner A and A did not confess against B, then B goes out of prison, and A could spend 10 years in prison [52].
4) If both of them did not confess against each other, both could spend 2 years in prison, for example [52].

However, please note that the number representing years charged for each prisoner here are just examples for illustration purposes, but different papers may use different ways of expressing the idea of prisoner dilemma. Also, while playing in different settings, there may be different number of years or representations.

This game reflects many important aspects of trust, and the most important point to note is that the best outcome for both prisoners comes when they both collaborate and do not betray each other (not admit the crime against each other), but any other scenario will hold a bad outcome for one or both of them [10, pp.210-213], [51], [52], [53].

Another interesting point to note reminds me with one of the most important factors in trust process mentioned in [11] which is accepting to take risk in the trust process. This is the case with both prisoners, so A, for example does not know what his friend (B, for example) had said before him, so he is technically in a very risky situation. If he puts his trust in his friend and decides not to betray him, he may end up with long time in prison while B will be out and free (if B had betrayed him and confessed the crime), so prisoner A (by trusting prisoner B), he makes himself vulnerable to the possibility of being convicted in prison the longest time. On the other hand, if prisoner B was really trustworthy and did not confess, prisoner A would have made the right decision, and both of them will serve just short time in prison. The same scenario can be applied with the case of prisoner B.

According to [51], it is usually the case to to play prisoner dilemma more than just once so that gives the players adequate time to get to know each other and learn how to act accordingly.

In general, people usually have the intention to cooperate but conditionally, so they look at their partner trying to spot signs of his willing for collaboration [10, p.245]. Some of the clues people use may be the face, gender, race in addition to verbal or non-verbal communication if this is available to them according to [10, pp.245-268].

I think this is a vital idea for us, computer scientists, since it is used unintentionally in the online world today. People are repeatedly looking for signs to help them in evaluating their partner on the other side of the screen, and maybe on the other side of equator. This information even if it is simple may give them a clue whether to proceed forward with this person or not.

In scenarios like these, we come to the importance of the mapping stage in our work as computer scientists. In this stage, computer scientists have to be clever in capturing trust information and looking for clues in exactly the same way human use in their everyday life, especially online.

Finally, it is interesting that sometimes the factors affecting cooperation levels differ depending on the nationalities, and this has been concluded in [54] after some experiments that involved people from different countries like USA, Korea, Japan, in addition to China.

5.4.1 Discussion and Experiment

As I mentioned earlier, the concept of reciprocity was not studied in the discussed model, so relations were studied on the basis of one direction. However, building on the facts mentioned above and the importance of reciprocity to social scientists, I wanted to see if there is any reciprocity working in the snapshot collected in [1] for Epinions and [2] for Twitter, and how this reciprocity (if present) correlates with the level of trust between users, so we run a small experiment on these two datasets.

I will just explain the experimental settings of Twitter dataset because Epinions is kind of similar. As we see from Fig. 2 below, if there is a relation or a tweet from A to B and then there is a reply back from B to A, there is some kind of reciprocity, and this reciprocity is generating some kind of loop. Thus, I thought maybe by capturing the number of loops between users, I can judge how much reciprocity there is in the snapshot, and by capturing the level of trust between the users in these loops, I can judge how this reciprocity is affecting the level of trust between the cooperating users.

Figure 2. Exchanging tweets

In order to capture the level of trust between users, we have to capture the two metrics proposed in the discussed model to capture trust, which as I mentioned earlier the impression (m) and the confidence (c). For the confidence, we just capture cases with

high confidence so c>=0.7 and in this case we guarantee that the results are kind of accurate. Then two different thresholds of impression metric (m) were examined in order to get some variations in the results, and observe if that will make any difference in the results at all. In the first threshold, m1 is considered high if it is >=0.5 and low if it is less than 0.5. The second threshold is where high m1 is >=0.75 and low m2 <=0.25.

Running the experiment, we got the results plot in the Tables 1 and Table 2 for Twitter and Epinions dataset respectively. Looking at the first row in Table 1 for Twitter (cases of first threshold), we notice that when first user A tweets second user B, and he has a good level of trust or relation with him (m1 >=0.5), we get 1132 loops where the second user B tweets A back (or has an impression about A) that is not high enough because (m< 0.5). In other words (m2 from B to A is lower than m1 from A to B), which I assume it represents less trust from B to A. The same is for the third row (second threshold) representing cases with high-low relations where we get 726 loops. However, comparing the number of these results with the number of loops with high-high impression, we notice that we have higher number of loops with high-high than loops with high- low. For example, there is 3598 cases in first threshold and 3309 cases of second threshold in Twitter data where A reciprocate/communicate/trust/tweet B with high m1 and high c>=0.7 (good trust), and B replies back with the same degree or maybe higher level of trust m2. In other words, we have higher number of loops with high m1 and high m2 compared to the low number of loops with high m1 and low m2. This result is consistent between the first and second threshold and it is also consistent between Twitter and Epinions dataset. This consistency between the two datasets gives our results more reliability.

Table 1. Reciprocity Loops in Twitter Dataset

Twitter Dataset First Threshold	
Number of loops with High m1>=0.5 and Low m2 < 0.5	1132
Number of loops with High m1>=0.5 and High m2 >=0.5	3598
Twitter Dataset Second Threshold	
Number of loops with High m1>=0.75 and Low m2 <= 0.25	726
Number of loops with High m1 >=0.75 and High m2 >=0.75	3309

Table 2. Reciprocity Loops in Epinions Dataset

Epinions Dataset First Threshold	
Number of loops with High m1>=0.5 and Low m2 < 0.5	646
Number of loops with High m1>=0.5 and High m2 >=0.5	602567
Epinions Dataset Second Threshold	
Number of loops with High m1>=0.75 and Low m2 <= 0.25	0
Number of loops with High m1 >=0.75 and High m2 >=0.75	597514

From the findings above we can say that it looks like we have good level of reciprocity between the users in both snapshots and maybe that is why we got high number of loops in both thresholds in each dataset. Also, when this reciprocity was present, it enhanced the level of trust between the cooperating users, why? Because most of the cases we got, when A tweets B and has high level of trust m1, we have B tweets A back with same or even higher level of trust m2. In fact in Epinions, in the second threshold we have zero cases where m1 is good (>=0.75) while m2 is low (<=0.25).

This shows that trust level (which is represented by m1, m2 in our case) is going higher or enhanced between the cooperating users (which means in the resulting loops).

These findings support the strong relation between trust and reciprocity as I just explained earlier from social scientists points of view. It also demonstrates that there is a tendency to reciprocate in human nature behavior as shown in [50], for example. Now we cannot tell for sure whether the trust that was already there between some users increased the reciprocity between them, or whether the reciprocity between them increased the level of trust; we can just capture the final results for the mutual relation between the two concepts.

We can summarize that in these two small tested snapshots, there is some kind of reciprocated interaction happening between two sides, and this kind of results actually support the concept of balance theory (explained in section 6.2.4) because it shows how both sides at least have some kind of shared trust, so their relation is free of tension and is balanced, and this kind of results were also supported and mentioned in [55] during their experiment testing balance versus status theory on some dataset.

I think that this kind of results motivates us to incorporate the concept of reciprocity in the mapping stage in the discussed model trying to capture relations in both directions between pairs of users. I think there is an advantage of including this kind of effects in the mapping stage. Basically, doing that will help us to judge more accurately the reason behind low or high level of trust between some users.

Fig. 3 and Fig. 4 below show the difference between two cases, so for example Fig. 3 show that A and B are very active in exchanging tweets and cooperating between each other, so maybe this could be the reason behind high level of trust between them at

the end (represented by red bold line between A and B), but Fig. 4 shows that A and B are not very actively cooperating (at least from B side), so maybe this could be the reason behind low level of trust between both of them (represented by black dashed line). However, we will not be able to capture the reason behind this final level of trust between pairs of users unless we capture relations in both directions in the mapping stage; in other words, reciprocity must be included in the mapping stage of the discussed model in order to get more accurate results about how trust is built between pairs of users.

For example, we should pay more attention to the exact number of tweets exchanged between the two interacting sides and see how this number affects the trust level between them. This study would be in the heart of trust dynamic, and studying this information in time or at least with a close observation will give us a better idea about the role reciprocity plays in building trust.

Figure 3. Mutual exchange of tweets

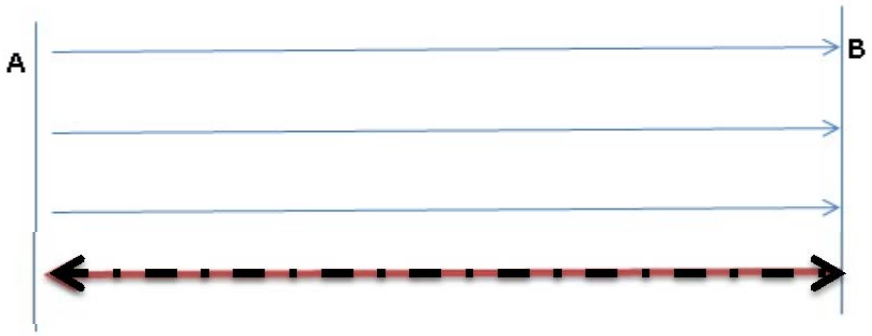

Figure 4. One-sided tweets exchange

One final note is that there is a possibility that these exchanged tweets are negative in content. In this case, exchanging even 100 tweets will decrease trust instead of increasing it. Therefore, sentiment analysis and content related studies should be combined with the other methods in order to come up with more accurate results and explanations.

Now that we have covered the most important factors that should be incorporated in the mapping stage, we will move to the next chapter to talk about management stage.

CHAPTER 6. TRUST MANAGEMENT

In the previous chapter, I discussed some concepts related to trust mapping, and the next step in processing trust is the stage of trust management, which focuses mostly on how to propagate trust over the entire studied network using the proposed metrics from the mapping stage, where propagating trust can be done using the concepts of transitivity and aggregation [2].

Usually, the best way to judge if the person is trustworthy or not is by interacting with him directly yourself and this is called first-hand or direct experience [34]. However, in today's expanding network, with hundred thousand of people joining every day, it is not feasible only to depend on the limited number of direct connections, so here it comes to the need to depend on indirect experience represented by transitivity [34].

As I mentioned earlier, our discussed model is built on the basis that trust is transitive, and the model was tested on Epinions dataset snapshot in [1] and it proved to be able to predict indirect trust between users in high accuracy (error in prediction was small) using concepts of transitivity and aggregation.

Before I move on to what social scientists think about transitivity concept, I would like to list some of the thoughts in this matter from other people in the field of computer science.

6.1 A Brief Look on Transitivity in Computer Science

There are many papers and researchers who talk about transitivity and use it in their models and frameworks where transitivity may take different forms. For example, in [5, p.39], they talk about transitivity being related to recommendation or suggestion made from B toward A about C. The author in [5, p.40] went on also to add the difference between referral trust where you trust someone to be able to refer another person to you in a specific domain (trust here depend on second hand experience), and functional trust when you really trust this person to do the real job to you, so it mostly depends on direct experience with the other side, and the same concepts are discussed in [3].

In [42], they also discuss the concept of transitivity as a recommendation from one person to another under certain situations, and they explain how this process of recommendation should work, especially when the chain of trust get longer. They try to come up with some measures that match the subjective nature of trust, and they discuss the concept of aggregation where information is received from more than one source. Time, context and confidence were listed as main elements in trust forming in [42]. At the end, they came up in [42] with an algorithm that is able to derive trust, especially from many recommending paths after evaluating these paths and recommenders, and identify the accuracy of each one using some kind of authenticity verification methods.

In [3], they describe the conditions under which trust is transitive where all paths should have the same purpose and that referral (when you refer someone to someone else you trust to do the required job) should depend on direct personal experience in order to avoid error in extracting trust value.

In [15], a new network structure was proposed that has new factors affecting the work of transitivity. The concept of transitivity decay was considered in [15] where the trust along the transitive path will decline the longer the path gets.

It is interesting to note, however, that not all computer scientists agree with the idea of trust transitivity. Marsh's work in [16] for example, whose paper was widely cited by many researchers, believes that trust is not transitive in general, and he states that the trust between A, B then between B, C cannot predict the trust that A will have toward C as a result.

Another interesting paper that is widely cited by many researchers is the one in [56], where they argue that trust is not transitive per se, but that there are many concepts that work in the same manner of transitivity and, in turn, are mixed up with transitivity concept and the way it works.

In [30], they also study trust and its transitivity in the field of computer science trying to come up with a logical theory behind that and formalize a semantic for trust. They define two types of trust: trust in belief and trust in performance. They used different illustrating scenarios, some formulas and theorems afterward and proved that trust in belief is transitive whereas trust in performance is not [30].

These were just small snapshots of some of the computer scientists work about transitivity, but I will not go further than that in this because my goal is to focus on what social scientists think about this important concept of trust, and this is done in the following sections.

6.2 Transitivity in Social Sciences

So after all the talk about transitivity, what do social scientists think about this matter? Does their work support that of the computer science field or it is contradicted? Is trust really transitive, and in which setup? The following sub-sections will shed the light on some basic ideas related to that matter.

6.2.1 Transitivity and Content/Context

For people in the psychology field, they argue that trust is not transitive in general because it depends on the content of trust, or the specific task/area of it, as it is mentioned in [9, pp.147-190], [41].

They think that for transitivity to happen, it is not enough just to trust a person about specific task, but you have to trust his opinion about suggesting another person or thing to you, which means his competence in a specific field, and in this case transitivity can hold [41]. As I mentioned earlier in section 5.1 when talking about the relation between trust and content, these points should be taken into consideration when conducting experiments and data analysis. In fact, we will not get accurate results when studying transitivity unless we take content into consideration. Thus, when evaluating triangles for transitivity, all edges on the transitive path should be filtered in a way that they all depend on the same kind of content or purpose.

In [9, p.168] they also give an example about how influential person can play a big role in enforcing his opinion about another person or thing to another person who trust him so much in a specific content or domain. For example, if A trust B and B is an

expert or a powerful influential person in a specific domain, B can simply influence A to trust C. This can be considered just a special case of transitivity because in my opinion people do not always deal with influential people for opinions in their daily lives. They often turn to their trusted friends for opinions. Now, if these friends are influential, this is considered another bonus to strengthen transitivity. An influential person may be a famous person, so you do not have to know him in person, just knowing him remotely influence you.

6.2.2 Transitivity through the Effects of Third Parties

According to [39], [48] third party is simply a third person or group of people between two agents along the way of trust, and these middle people may know (or being known) by both sides to some degree. For example, if we have the triangle of ABC, B could be considered a third party between A and C, and this is shown in Fig. 5 below. Sometimes, this third party will be monitoring let us say a person A and transferring the information about its behavior to C; this kind of information circulating between A and C or other parts is called gossip according to [48] and [57].

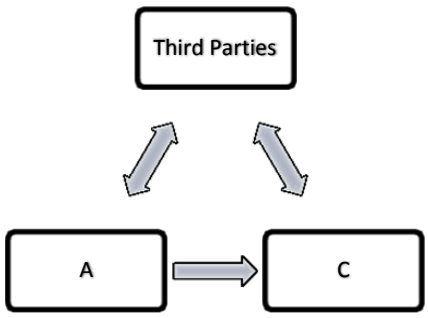

Figure 5. Third parties between A and C

The role of third parties is discussed in many papers, and I think one of the most notable papers is the one in [48]. This paper is in the field of Business and Economy/sociology, and it is to show the powerful effects of third parties and gossip in the network on the trust level in the relationship between two agents (they called them Ego and Alter). They argued how these third parties between two agents make them more attentive and sure about their decision about whether to trust or distrust each other. They studied a group of 248 senior managers and their relations in and outside their companies resulting in 3584 cited contacts. They simply built some kind of questionaries' in a way that indirectly help in assessing the level of trust and distrust that these managers and their mentioned contacts hold toward each other, in addition to the role of third parties between them.

Five kinds of indirect connections were found in [48] that depending on its type influence the relation and trust level between the two interacting agents. I found that three of these mentioned indirect connections in [48] could support the concept of transitivity, so they are explained below:

1) One kind of indirect connection is the mutual friend who is very close friend to both sides, and this type of third party does support and increase the trust in a good way whether both sides are close friends already or they are distant [48] (and this kind of connection is called TP1 in [48]). According to [48], if both sides know each other before, the role of this mutual third party is to boost this trust between them, but if they are distant or they do not know each other, its role is to bring them together increasing the chance of trust between them. I think that this implies that trust is transitive in the presence of someone who is close to both sides (A and C for

example). This is because according to [48] if A asks this third party about C, this third party is more likely to tell good stories about C to A since he knows C well and trust him well. These good stories will result in more trust from A toward C, which in turn result in transitive trust from A to C through this third party effects.

2) Another kind of indirect connection that could be supporting transitivity is the one who is strongly connected with C (the second side), but weakly with A (the first side), so it is one close friend to C, but he got cited for being trustworthy by A as illustrated in [48] (and this kind of connection is called TP2 in [48]). I think that this type of connection implies that transitivity is working as well. This can be explained by the third party being a good friend with C, so she will transfer the good stories about C when A asks for her recommendation as shown in [48]. This process, then, generates a positive transitive trust.

3) Another type of connection suggested in [48] that I found it to support transitivity is the one strongly related to the first side and weakly to the second side (it is called TP4 in [48]). I think that this kind has something to do with negative transitivity in the sense that if A has a good relation with this third party, and this third party has some issues with C, so A will be affected as well through this transitivity and may lose her trust in C. According to [48], since this third party is not a good friend with C, she is more likely to recall negative experience about her affecting A's trust in C. This influence becomes even stronger if A has a previous negative experience with C, so third party' role here is to agree with A by relaying bad stories to support A's previous bad experience with C, which is called echo effects according to [57]. I think this means that even negative trust is transitive sometimes in the relations.

Another paper that talks about the effects of third party on trust is in [58], and it is also in the field of business and management. The work in [58] is special because it is studying trust with emphasis on social context [58], which by itself can have huge effects on trust. They categorized the ways that connect trustor and trustee into three types which are network closure, trust transferability, and structural equivalence, and each of these types has its own way in enhancing trust and affecting the relationship between trustor and trustee. I think this kind of study gives us another clue to stand on when studying transitivity as computer scientists, which simply recommend connecting transitivity and trust between people with network structure in which we perform our study. Networks with dense closure and the ones that are rooted in a strong third party effects are more likely to have stronger influence on increasing trust between people than networks with sparse closure as found in [57].

Also, from the study done in [39] (discussed earlier in section 5.2.1), it is noted that many factors affect the indirect opinion from A toward C: the amount of information A receives about C, and how much A trusts B (the third party) who is communicating this information to her.

The role of third parties is crucial not just when it comes to transitivity, but also when it comes to repairing relationships/ trust between conflicting sides. In [59], for example, it is shown through some experimental settings the crucial role and effects of third parties in rebuilding corrupted trust again.

6.2.3 Transitivity by Balance Theory

Now another support for the concept of transitivity comes from the field of phycology, and it is a well-known theory called the balance theory. Explaining the balance theory in a simple manner goes like the common saying that usually the friend of your friend becomes your friend as well, and his enemy is yours as well; also, if your enemy has a friend, you also consider him your enemy, but you consider the enemy of your enemy to be your friend [60], [61], [62], [63], [64].

The relationships in this theory were studied in the form of two entities such as two people, or in the form of triads such as the presence of (three people) or (two people and one common object, thing, or notion, etc.) which they both have some kind of relation with or feeling toward as explained in [62].

According to [60], [62], [64] there are two types of relations between these entities which are either (like L and its negation dislike ~ L) in addition to their derivatives (love, admire, etc.), or (U and its negation ~ U), where the relations here are similar to the action of owe, possess, etc..

Balance exist between two entities if they both share the same attitude (positive or negative) in all aspects related to the specific kind of relation they have together as mentioned in [60], [62].

In case of a triad, balance happens if all of its nodes share same positive attitude in their relation, or if they both hold the same negative attitude toward the third person or object in the triad [60], [62]. In other words, we can have two negative links and one positive in a triad to be balanced [60], [62], [61].

In every triad, there should be some kind of balance in the attitude the nodes share with each other in order to keep the triad away from psychological distress as discussed in [60], [61], [62]. Any case of imbalance between these three interdependent elements will create some kind of emotional discomfort in the relation, and this will trigger some kind of change to resolve this imbalance and bring the triad back to a stable state [64]. This change can be made between any of these three entities of triad, and it can also happen in the type of relation between them [64]. This is because if the imbalance continues and did not change, it will cause some kind of uncomfortable tension between the members [64], [62].

According to [65, p.14], many studies have been done following Heider theory of balance hoping to investigate the reasons behind this finding, and many sociograms were tested for the same matter and proved to be balanced. Also, it is stated in [65, p.14] that transitivity was one of many essential concepts that researchers came on to develop after Heider theory of balance. Thus, this theory can provide a very essential support for the presence of transitivity.

Let us illustrate the concept of balance theory with a simple example: if A (Likes) B, and B (Likes) C, so A will (Like) C. This represents three positive edges, so it is a balanced triad according to balance theory papers above. A, B could be two people while C may be an object, or person that they both have to evaluate. Another example with two negative edges and one positive is when A (Likes) B and B (Dislikes) C, so A will (Dislike) C. This can be explained as the enemy of my friend being my enemy, and this is also considered to be a balanced triad as explained above. An example of unbalanced triad would be when A (Likes) B and B (Likes) C, but A does NOT like C. This situation

will create some kind of tension and pressure in the relation and may lead some actors to change their attitude in some way or another to resolve the tension as I illustrated above referring to some balance theory papers. For example, A may compromise since she is a good friend with B, and she learned that B likes C, so A may accept to change her attitude toward C in a positive way resolving this discomfort in the triangle and restoring some balance. The other compromise could result by B changing her attitude toward C, and stop liking C in order to go with A's opinion (restoring the balance again in this case). The bottom line is that people like to maintain consistency in their relations with each other, which gives the relation its stability and comfort [61].

6.2.4 Time Effects on Triads Transformation toward Balance

Time has a big effect on the transformation of triads toward balanced state, and in turn toward transitivity, and this is tested in a study done in [66], where they tried to see the number and kind of triads that move (or do not move) toward balanced state over time. They did an experiment trying to test the "Fundamental Structural Balance Hypothesis" (FSBH), which argues how over time signed networks move to be balanced [66] and that the occurrence and frequency of balanced triads will be more than the occurrence and frequency of imbalanced ones increasing the overall balanced state in the network over time [66]. The experiment lasted around fifteen weeks (a semester) between seventeen participants who repeatedly evaluated each other over the time of the experiment. In their classifications of triangles, they depended on Heider classification in [60], [62].

In our group work, we did a small experiment trying to see how much FSBH (explained in [66]), balance, and transitivity are supported in the snapshots collected in [1]

and [2] for Epinions and Twitter respectively. The goal is to test our work from social scientists point of view and compare our results with their results to see where we are at.

First, for the confidence metric we just consider the triads with high confidence (C >=0.7), and for the impression metric we consider the link to be positive (Like) if the impression (m >= 0.6) and negative (Dislike) in other cases.

Looking at the results in both Table 3 and Table 4, we find some kind of consistency in the resulting number of triads and their occurrence in the network, and the results in these tables are for all types of eight triangles. However, since our focus is on transitivity concept, we are not really interested triads that start with D (Dislike). This is because one of the most important factors in transitivity is the presence of LIKE on the first link, so if the first link is negative (Dislike), transitivity study does not apply from the first place. Thus, Table 5 reports the results that are just related to triangles starting with (Like) on the first link for both datasets Epinions and Twitter.

Table 3. The Number of Triangles in Twitter Dataset

The Type of Triad	**The Number of Triads in Twitter with High Confidence**
LLL	2216
LDL	713
DLD	507
DLL	413
LLD	366
DDD	448
LDD	220
DDL	280

Table 4. The Number of Triangles in Epinions Dataset

The Type of Triad	The Number of Triads in Epinions with High Confidence
LLL	1,401,283
LDL	105,079
DLD	3,210
DLL	71,243
LLD	14,443
DDD	0
LDD	12,739
DDL	0

Table 5. Frequency of Occurrence of Triangles Starting with L

The Type of Triad	Balanced or Not	Triads in Epinions	Triads in Twitter
LLL	Yes	1,401,283	2216
LLD	No	14,443	366
LDD	Yes	12,739	220
LDL	No	105,079	713

1) In [66], they found that the frequency of occurrence of the two balanced triads (LLL, LDD) has moved in a way that supports the fundamental structural balance theory, so their incidence increased by time [66]. In our snapshots in Table 5, we notice that in both datasets we also have a high number of LLL triangle incidences at the time of

collecting the data in both datasets. In fact most cases we had in our two snapshots are from the kind LLL, so it has the highest occurrence among all other triads. This is encouraging because it proves how transitivity (which is a special case of balance) exists in the network, especially when the first two links are positive. The incidence of LDD, however, is not as high as we anticipated it to be as opposed to what is expected from a balanced triad like this to have high frequency at the end of the experiment, so this result contradict with FSBH discussed in [66].

2) They also found in [66] that the frequency of occurrence for these two imbalanced triads (LLD, LDL) has lessened over time which agrees with FSBH as well. Looking at our results in Table 5 we notice that the counts of imbalanced LLD is not high in both datasets, but still it is higher than other types of triads that are supposed to have more incidences like LDD. Another surprising result is the high occurrence of the triad from the type LDL which is considered imbalanced so it should not happen very frequently in the network. This kind of result contradicts with the concept of transitivity and balanced relations.
3) Overall, however, balanced triads counts were higher than imbalanced triad's counts in both snapshots where we have 3223 balanced triads in Twitter compared to 1429 unbalanced ones, and 1417232 balanced triads in Epinions compared to 190765 unbalanced ones, and this is considered a promising finding.

So what could be the reason behind some of the troublesome we found in our results, especially the high occurrence of the imbalanced triangle LDL vs the low occurrence of the balanced one LDD. There is a very important point to be noted here which is the dynamic nature of their data versus the static nature of ours. To illustrate, the

experiment in [66] was done considering the effects of timing and how these triads move and change through different times. However, we do not have the same feature in our experiment since the study was done on a snapshot at a specific time so we rely just on the final results from the snapshot obtained. Maybe repeating the same study again on a different snapshot taken at a later time than the previous ones (or the same snapshot at different time stamps) can reveal some positive transformation that some triads can achieve over time. For example, these same balanced triads that had lower frequency in our experiment may increase in number by time, and the imbalanced ones may decrease.

However, it was easier for the study in [66] to be done dynamically due to the small number of people participating in the study, where all started and finished at the same time. However, this is not an easy task to do with huge number of users in the online world, where it is hard to capture the dynamic relationship between people (since every minute there are many people leaving the network and new others are joining). The network in [66], also, is all built from scratch, and this help a lot in capturing all the details from the beginning of the study to the end, and how balance works through time.

Another reason behind the discrepancy in our results could be that we mainly depend on some trust metrics to capture trust information from the network, and this may not be sufficient enough to capture all details about how trust relations are evolving between some users. On the other hand, this kind of information is easier to obtain when the experiment is done with people in real life and not online because the reason behind all kinds of generated relations among these users will be more evident, which is something we are not able to achieve easily in the online world.

I think this motivates us to do more work in the mapping stage to include more metrics or implement better tools hoping to capture more data about how some trust relations are emerging between users in the online world.

Finally, it is found in [66] that there must be a relation between (some actors' personality features, inequality in popularity factors), and (the high or low frequency of some triads). If this is the case, I think that it will be hard to obtain the same results on each collected data set. Thus, we could have had completely different results just by changing the dataset of the experiment and, in turn, the attitude of people in this dataset.

6.2.5 Inequality in Popularity

In [67], which is another social psychology paper, researchers also try to show how transitivity exists. However, this time they argue that contrary to what has been mentioned in other papers about the reason of transitivity being related specifically to balance theory, there is another pattern called inequality in popularity that can be responsible for creating that kind of transitive triads according to their study in [67]. They claim that this method and its implication are under-studied even though it seems to be an underlying reason behind some resulting transitive states [67]. It is argued that many studies support the claim that there is a high likelihood for users in social life to befriend the friends of their friends as well, but this is just explained on the light of balance theory which is not always the case [67].

In order to clarify this confusion, they did a study in [67] trying to deduce the triads formed by the participants from their answers to some sociometric questions, and they try to find the tendency of these triads to be balanced and transitive and analyze the

real reason behind it. They show in [67] that this is mostly not just due to the cognitive balance theory, but it is due to the inequality in popularity between people in these triads. According to [67], not all people will have the same likelihoods to be picked by others as friends; some are more likeable/ favorable, so they may have greater odds than others to be liked and selected as friends; others may not be preferred that much or at all if they are not likeable in nature, so they have low chances to be selected by others as friends.

In addition, they discuss how people tend to be gathered in clusters where they can most likely get together on something they all agree on or have interest in, so people will be more likely to choose those who are more similar to them than others in terms of what they like or agree on [67]. Also, in clusters like these people usually tend to imitate each other [67]. For example, if someone is famous enough and likeable by others, most people will tend to imitate each other and form a relation with that particular person again and again, while if someone is not chosen by anyone, there is a big chance that he will not be chosen at all later on (considering that people are imitating each other by not choosing this person) [67]. Factors like these all together contribute to the fact of inequality in popularity, and in turn to the formation of transitive and balanced triangles in a way that is not really related to the balance theory [67].

On the light of what is mentioned above, researchers in [67] insist about the role of this factor to be studied as an underlying cause behind the formation of some clusters or the frequency of some type of triads.

6.2.6 Transitivity in Different Sociograms Settings

Many researchers in the field of sociology and psychology got motivated to support the theory of Heider about the balance that sentiment relations in general achieve over time in an effort to maintain some stabilities in the cognitive state of the members in these relations (so tension does not arise between them), and these social scientists' studies were good to provide this kind of support [68].

Their results are quite promising for us, as computer scientists, when it comes to supporting the idea of transitivity as a general theme in sentiment networks. Many studies done on the relations between people revealed a high tendency toward transitivity in environments where the relations are sentimental in nature [68], [69], [70], [71], [72].

According to [68], [70], this kind of sentimental relations are found to have fewer intransitivity occurrence compared to non-sentiment relations, where the relations are less intense and less intimate in nature.

In [73], they discuss some of the consequences related to Heider theory of sentiment relations' balance and transitivity. They claim that the presence of such balance results in some kind of stabilities in the relations between the members because they will have some kind of consistencies in their opinions and relations. However, the absence of such transitive and balanced state creates some kind of instability and un-satisfaction in the sentiment relations between these people. This is because this situation will generate some forces aiming to change the intransitive state to a transitive balanced one in order to resolve the tension in the relation and regain psychological comfort.

Many methods have been used to capture transitive and intransitive cases and measure their probability. In most of these studies, researchers depended on comparing the results from their specific empirical sociogram with an ideal random model to evaluate tendency toward transitivity in their empirical data [73].

In other studies, they use different metrics to capture balance and transitivity. For example, tendency toward transitivity is a metric that was used in a study done for similar matter in [69], and the degree of transitivity for each sociogram is another metric that was also used in [70].

The two metrics mentioned above got combined and adopted by many later studies in order to analyze transitivity in different sociograms such as the work done in [68]. They stated in [68] that there is not much work done to study transitivity in a context different than sentiment and friendships, so they tried to test it in two different settings which are sentiment and work based environments. Thus, they have done their study on different sociograms of 24 elementary schools asking questions on two different levels: either sentiment based questions like choosing best friends, or work-based questions like choosing people to discuss some school work matters with.

They found common tendency toward transitivity in both sociograms settings, so transitivity exists in both sociometric fields to some degree according to [68], but there is a slight difference in the results between the two metrics researchers used in their study to analyze transitivity and balance. For example, they were hoping, as most of the above study showed, to find that sentiment based sociograms have greater degree of transitivity with higher tendency toward it compared to work based environment. However, the results were surprising as argued in [68] because even though they have found a good

tendency toward transitivity in both cases, but testing the first metric they found that the work based environment has higher tendency toward transitivity than sentiment based environment. However, applying the second metric which is the degree of transitivity they have found what they expected about the sentiment based environment having higher degree of transitivity. However, the overall look at the results from both metrics reveal that transitivity seems to be a common property and feature in both sociograms (sentiment and work based environments).

The previous study done in [68] correlates to some degree with another one done in [70]. In the latter, they also studied different metrics related to measuring transitivity, especially the tendency toward transitivity and the degree of transitivity, among others. They also discussed the best way to form questions to be asked for participants in order to reduce or even avoid errors in transitivity measurement, where free choice questions are suggested to be better than the restricted choices and produced less intransitivity [70]. They tested their theories on a set of data containing fifty one sociograms, and they also found that there is a tendency toward transitivity and less intransitivity in sentiment based sociograms with the presence of some intransitive triads at the same time, so the presence of this kind of triads seems to be inevitable [70].

When using a technique called tracing, they found that a high percentage of their intransitive triads on the best friend level became transitive again (even if just partially) at a less intense level of relation, and the same kind of technique was used in [68] with the same kind of promising results. They argued in [70] that this is because intransitivity in strong relationships causes a lot of tension that has to be relieved someway, and this can usually be done at a lower level. The occurrence of intransitivity in general and the

unresolved intransitivity at a less intense level of a relation can sometimes be related to the personality and attitude of some people who are isolate in nature as argued in [70].

I think that these findings have to be taken into consideration when talking about transitivity or intransitivity in our experiments as computer scientists. People's personality has to be considered sometimes in addition to the nature of the network, which gives us a lot of insight of what to expect.

It is worth mentioning, however, that some of these studies are criticized by having some errors in the way data was collected, tackled, analyzed, or the way participants were questioned [74], [75]. For example, questions with limited number of choices in the answers were found to introduce some kind of error in the results, and this seem to be avoided by introducing free choices answers as shown in [70], [74], [75].

It is outside the scope of this thesis, however, to study the topic of measurement errors of transitivity in social sciences fields. My focus is on the final results, but I wanted to mention some of the drawbacks that may have faced researchers through the course of their work, so that computer scientists become more vigilant when analyzing similar issues or comparing their results with existing ones.

Finally, it is noted that most of social sciences studies seem to agree to support transitivity as a main standard and structural property that arranges sentiment relations in general [68], [73], [76].

6.2.7 Transitivity by Status Theory

Another theory that plays an important role in transitivity concept is called status theory. Similarly to balance theory, this theory also studies trust relations between people,

and it mainly deals with nodes' rankings as a way to link different edges to each other [2]. So when a link is said to be positive in the direction from Y to Z for example, it means that Y looks at Z in a way that Z is in a higher ranking or better status than her (Y), but Z may look at Y as a person who has lower ranking than her, so Z mostly may link to Y negatively [2], [55]. Depending on this definition, it looks like LLL is a good triad that satisfies these effects of rankings, which happens also to be a satisfying triad for the balance theory, but other triads' cases may be good in one theory but not in another [2].

According to [2], people in different situations may act differently, so that is why status theory may be more satisfied in one dataset snapshot and not another, and the same can be applied for the balance theory effects. In [55] they also tested the effects of balance and status theory on datasets taken from Wikipedia, Slashdot, and Epinions, and they found how each dataset can fit a specific theory better than it fits another depending on the specific settings under which the dataset is studied and represented, and whether the links in the studied graphs are considered to be directed or not.

The status theory is kind of connected to how transitivity is working in a network according to some social scientists, especially in the sociology field.

According to [73], the transitivity of sentiment relations feature in a group have some essential consequences on how the structure in that group will turn out to be because it has been shown that a sociogram with all transitive relations (without intransitivity) means that the sociogram can be clustered into cliques with ranking structure (groups of cliques that are ranked hierarchically) where the nodes of higher status have higher rankings than the ones with lower status.

The use of clique comes from the fact that sometimes people have reciprocated relations between each other, but the use of hierarchies comes from the fact that sometimes people make unequal (non-mutual, non-reciprocated) selections, which make some of them to have higher status and others to have lower status [73]. For example, if we have a positive relation from A to B, that means that B has a higher status than A, so it does not necessarily mean we will have mutual positive relation back from B to A because B may considers A to have a lower status than her, so the relation from B to A is most likely to be negative. However, if both A, B share the same negative or positive attitude toward each other, their relation is considered as mutual or reciprocated relation.

This structural finding is proved by some work done by some sociologists using concepts related to graph theory. For example, in [72], they categorized the relations to be either mutual or non-mutual, and the mutual could be positive or not positive, which results in different triads possibilities. Mutual positive relations link people from the same clique at the same level, while the mutual negative relations link people from different cliques at the same level as well. The asymmetric non-mutual ones, however, attach people from different levels, and the person receiving the positive relation has higher order or status than the one generating it.

Basically in [72], the authors were trying to examine the propositions of Homans and apply that to a model built in a way that support these propositions, so basically translating Homan propositions into a model. What is interesting about Homan propositions is that they also explain how relationships form between groups of people in a way that resemble cliques and ranked hierarchies, so Homan’s ideas could be easily reflected on the concept of status theory.

While testing their findings in [72], they used a random graph model with which they compared and tested their theories on 427 sociograms. They found a good proof for Homan theory because they showed that by having mainly transitive relations, we get a structure that resembles hierarchies of cliques (which is the result of people having different status within their relationships with others). They also showed how transitivity happens more frequently than what would be anticipated to happen by chance. However, they also argued that in order to be able to get this kind of structure (ranked cliques arranged hierarchically with transitive relations), specific kinds of troublesome triads have to be not present. In other words, it is supposed that these specific kinds of triangles occur less often than what would be anticipated to happen by chance in the random model they used for comparison. In fact, this was the case when they tested their model because the frequency of such triads was mostly very low compared to what would be expected to occur in the random model.

The bottom line is that their result is promising in supporting the presence of transitivity under the effects of status theory.

6.3 Aggregation

In real life, when you ask about someone, you are likely to receive multiple points of view about him/her from different people through your social connections. In cases like this, you are most likely to consider all these opinions and do some filtering out and some logic judgment in order to come up with your final decision. This process of combining results from multiple sources is called aggregation in the language of computer science.

Fig. 6 below for example is a simple illustration of what the concept means. In this figure, Bob asks about Alice and he receives information about her from multiple friends (Sara, Jess, Alex, and Ella in this figure). The number of these sources varies from one situation to another. Also, the type of this information varies from one source to another. Bob may receive some good information along with some bad ones about Alice. It may be all good trusting information that encourages Bob to trust Alice; on the other hand, it may be all negative experiences which demotivate Bob to trust Alice. The trickiest case, though, is when Bob receives contradicting information about the same person Alice from different people. However, in all cases Bob has to weigh the information he receives depending on factors, he thinks, they are important to him. One factor could be, for example, is how much he trusts the people who gave him their opinions, and then he acts accordingly.

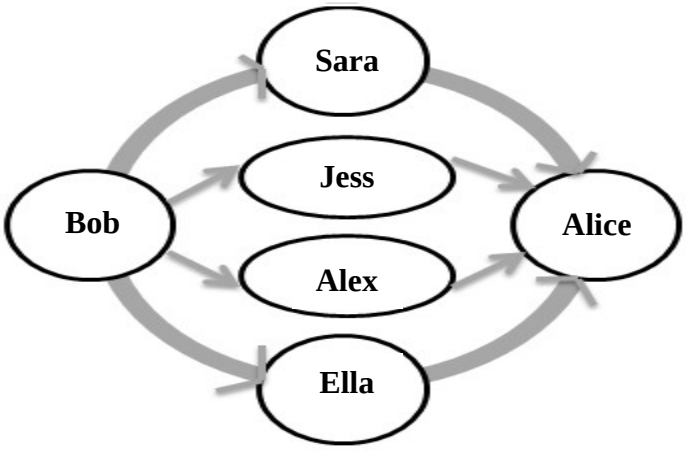

Figure 6. Multiple paths between two parties

As I mentioned earlier, in [1] they use two principles for aggregation that they consider them to be psychologically based; I have found some justification for the use of these principles from social sciences' points of view, and that will be discussed below.

6.3.1 Discussion of the First Principle

The first principle states that if same kind of information about the target is received from multiple sources, the confidence in this target will increase [1].

This idea is supported directly or indirectly by some social scientists. Indirect support means that sometimes social scientists use their own language in their studies or they may do some experiments for other purposes than the one I am looking for. My job, however, is to infer from their results what can be applied to our situation.

In [39], they proved through their longitudinal experiment how people are usually influenced by the number of sources they provide them with information about the person they are trying to evaluate. This is especially true in case that this information comes from trusted third parties who convey this information about the other side. Thus, more positive/negative information from trusted conduits contributes with increased/decreased levels on trust that the source will have toward the destination [39]. These findings support the first principle indirectly because it shows how person A, by receiving multiple information about person B from people he trusts, becomes more confident about his decision on whether to trust or distrust him (depending on whether he receives positive or negative information).

In [48], the author proved the role of third parties in affecting the trust levels between two people. He showed how being surrounded by a network of strong third

parties make people more clear and certain about their trust decisions about each other. This certainty is stronger the more third parties available to convey similar kind of information to one person about the other according to [48]. This certainty can be translated to confidence in our case, so it supports the first principle.

In another paper in the field of psychology found in [41], researchers stated that people usually feel more encouraged to trust something or someone that is trusted by many others. For them this indicates that this person or object is credible because it has proved to be trustworthy to these many people, so it is worth to be trusted again as well [41]. This support the first principle as well because it shows how that many similar information is increasing the safety level (which represents confidence) that people have in their decision to trust.

In [58], they also support the first principle by showing how when people have access to many trusted sources of information about the other side, they will have a more thorough look, and it will increase their trust level and confidence about the person they are receiving information about.

I would like to point here to the difference between confidence and trust. The two concepts may be easily confused together while there is a difference between them. The confidence in our decision increases regardless of the trust we hold toward another person. It means how much we are sure about the decision we make toward a specific person whether to trust or distrust him [1]. For instance, more negative stories or experiences encountered by a person interacting with B, for example, may increase the confidence of this person about his decision to distrust B. In this case, the confidence is higher even though the trust level in B is indeed lower.

6.3.2 Discussion of the Second Principle

The second principle: states that receiving opposite trust information about the same target from multiple sources results in reducing the confidence a person has about this target [1].

Many papers in social sciences fields talk about the effects of receiving positive and negative information at the same time about the same person or matter, where it is shown how the negative information usually has stronger impact and more profound effects in decreasing the level of trust in that person [26], [39]. However, they did not talk directly about the drop in confidence level, so the focus was mainly on the level of trust that looks to be affected when receiving bad information along with the good ones.

In [77], the author explains the reasons behind the theory on why it is easier for trust to be destroyed compared to how slowly it can be built. He discussed many types, levels, and stages of trust that affect its fragility or resilience within the relationship. Depending on such factors, the degree of trust destruction differs. Negative experiences may affect certain kinds of relationships more severely than it affects others depending on the kind of bond, trust relation between the two sides [77]. He mentioned a very interesting point about the conclusion related to trust fragility where he links this theory to trust being studied in experimental environment where participants barely knows each other or not at all. Even when these participants build some kind of trust through the time of the experiment, it is not strong enough to sustain the bad effects that they may encounter later on according to [77]. However, the results could be completely different when studying the same situation between close friends who know each other well and

who may tolerate some kind of bad effects on trust without affecting their trust in their close friends [77]. I think that these points should be taken into consideration when evaluating the effect of bad information on trust.

6.3.3 Assigning Weight to the Parallel Paths

When talking about receiving information from different sources about someone, it is feasible to ask how to weigh these different experiences in the aggregating paths. Some studies and surveys support the idea that more weight should of course go to the people who are closest to the trustor emotionally (such as best friends relations) [15], [78].

This actually makes sense in real life because when you ask many people around you about a third person you are about to interact with, you get all different feedbacks from them, but you filter depending on your relationship with these people who gave you their opinions. It is obvious that you will give more weight to the opinion of your best friend about a person more than the opinion you receive from another friend you do not consider that much close.

In a study done online by Forrester Research in [79], they have found that 70% of people trust what their friends recommend about brands more than the ones announced by the brand itself which is only trusted by 10%. This gives insight about the weight that should go to the opinion of closet people when receiving recommendations from different paths during the aggregation process. The same idea is supported by a study done in [39] stating how people take into consideration the opinions of people whom they trust most.

Sometimes, assigning weight can be done depending on factors other than just being closely friend with that person. Such factors include similarity, so more weight

should go to people who share similar choices or preferences like you [15], [29]. For example, you are more likely to trust the opinions of people you feel they have similar interest like you in a specific area because this may give you an insight that this person may also be close to you since you both share the same preferences/interests; this is actually considered as a main principle when studying trust in some papers like in [15].

When aggregating paths in the discussed model in [1] more weight was assigned to paths with higher confidence, where the confidence is captured from the number of interactions. This is because more interactions that take place between two people implies more experience and better knowledge between them, and in turn more confidence about the taken trust decision.

CHAPTER 7. DECISION MAKING

Now that the stages of trust mapping and management are discussed, the third step is making decision which includes using this obtained information in addition to some tools in order to help in making the final trust decision [2]. This helps to ensure some kind of certainty in the decision of whether to proceed in a specific action or not, to trust a specific person or not, but not all trust frameworks proposed by computer scientists deal with this stage.

In this chapter, I will focus on the role of reputation in decision making from some social scientists points of view since it seems to have a vital role in this step.

When dealing with online websites and shopping systems, there is a big chance that people are dealing with strangers they do not know anything about [3]. Thus, people start looking for some kind of reassurance, reliable information or pointers to help them with their decision. However, it is not always easy to obtain that, especially about people newly joining the network. In cases like these, the role of reputation stands out as a main motivator in online world interaction between people.

Reputation online has many methods to be done and achieved. Some scholars, for example, argue about gossip in social network being a kind of informal tool to help either in building or destroying reputation, in addition to third parties shown to be pivotal contributors in the reputation system in any network [43, pp.73-106].

A study done in [80] shows the role that reputation plays in building trust and promoting cooperation over the internet, especially among strangers who have not met or known each other before. Even though there was a good level of collaboration among participants without previous knowledge, this became even better when reputation information made available to them before taking their next decision [80].

They mainly depended on the image scoring game in their study in [80], where two players who do not know each other and will not meet another time in next games, play together in a way that helps in building their reputation. Assigning the players to play different roles and with different partner each time helps in monitoring the effects of indirect reciprocity and reputation building. There was full control over the amount and kind of information made available to participants in order to be able to monitor the role of reputation (when available) on the level of cooperation between them. The money value that participants are playing for was changed as well from one game to another in order to monitor how the change in cost (with or without reputation information) would affect the level of cooperation between participants.

They have found many interesting results, but I will summarize some that can be reflected on our work are:

1) They anticipated the cooperation to be good at the beginning of the game and to develop well between the participants, but when participants knew they were close to the end the game, their level cooperation declined no matter how much reputation data was available for them to depend on [80]. I think this shows how building a good reputation is a huge motivator in cooperating between people. Thus, when this motivator is not there, trust and cooperation will tend to decline.

2) Sometimes participants were willing to be cooperative even without knowing their partner and without knowing any information about his past reputation (good or bad), especially if the cost of their cooperation is not high, but if the process is costly, they prefer to have more information about their partner before risking money with maybe the wrong person [80]. This result is consistent with the results in the experiment done in [81], where participants in the experiment were also willing to cooperate even without having adequate information about their counterparts, so their cooperation helps in building trust and reputation for the future.
3) The interesting point about this experiment is examining the role of reputation (represented by the person's past interaction history) in boosting cooperation and building trust among strangers. For example, information about A's past action affects B's ability and probability to cooperate and trust him, where the probability to cooperate is higher if the reputation of A is good meaning his past actions reveals he was cooperative in nature when previously played with others as shown in [80]. Adding more detailed information to the available history of the agent was found to boost the cooperation level even more [80]. It is also interesting to know that people sometimes tend to treat their recent partner the same way they were treated in their last games, so if they had good experience in their last game, they are more likely to be cooperative with their recent counterpart, otherwise the opposite will be true [80].

I think that these findings reflects important points about how individuals react in online networks when they are about to make a decision to cooperate or not, and it shows the effects of reputation and the person's last experience on the level of cooperation.

In [81], we have another paper in the field of accounting and management, where the authors have done some similar job to the work in [80], but they used the investment game between 32 pairs of participants in order to study the influence of history and reputation on the level of trust and cooperation between people. This time, players were given the chance to play together the whole time, so researchers have a chance to observe the effects of reputation. Players had tendency to cooperate if their partner share the same attitude, so mutual trust was a key motivator in the cooperation process, in addition to the motivation to build a good reputation [81]. When history information is present, participants in the second room were more willing to send good amount of money back to their partners in the first room hoping that their action will help in marking them as trustworthy people and build their reputation [81]. When there was no reputation information available to participants, however, level of cooperation was much better in the first round of the game compared to the second time [81]. Sometimes, some people are trusting and cooperative in nature which influences the whole process of trust and cooperation [81].

There are many other ways in which reputation can affect the flow of information and decision in social networks, or in online networks in general, and one way according to [43] is by imitation. It has been argued in [43, p.44] that if A has learnt information about games played by her partner B with another person (C, for example), it will affect her decision about how to deal with him in next interaction encounter. This does not just stem from an imitation action; it also stems from some inferring action done by A about B and C [43, p.45]. In other words, A did infer that since C has investigated her money well with B, B must be trustworthy, so A will investigate more with her partner B in

order to gain the same benefits. Thinking about this scenario from different point of view, it reflects the role of reputation in an indirect way. Also, when participant were allowed to share feedbacks about their recent experiences with their partners and report whether it was good or bad, the trustworthy behavior got improved throughout the course of the experiment because participants were eager to gain a good reputation from these reported feedback as shown in [43, pp.43-64].

Incorporating the reputation in online systems is also proved to solve the lemon problem in the online word [43, Ch.3]. In the lemon problem, online sellers may be more inclined to cheat and make more money by selling defective products to the buyers who do not have a clear idea about the product that is going to be sent to them by these buyers [43, Ch.3]. This was the case when sellers in the experiment were given the chance and ability to constantly change their identity and no reputation information was available for buyers to rely on in their decision [43, Ch.3]. However, when this behavior was controlled and reputation information for each seller was available to buyers to use toward their decision, the lemon problem declined substantially [43, Ch.3].

Depending on the vital role that reputation plays in making decisions and building trust, many online website provide some kind of feedback system, and eBay system is one famous example about that [43, p.16], [82], [80].

Systems such as eBay basically gather information concerning the sellers past actions and behavior and make it available to the general population online, so they can depend on these sources when trying to evaluate their decisions [82]. These information is collected from previous assessments, rankings, and feedbacks provided by people who have encountered an experience with this particular seller and then wanted to give their

evaluation at the end of their experience [82]. Both sellers and buyers on eBay have the chance to evaluate each other after completing the auction, and the final reputation is the subtraction between the positive and negative comments given by different distinguished users [82]. When a new user joins the system, or an existing user changes his identity, they have to build their reputation feedback again from zero [82].

It has been shown that usually people are keen to pay more for reputable seller than to pay less to non-reputable or new one, so for example buyers tend to pay for a seller with a strong good reputation 8.1% more than to a one with a weaker reputation or to a new seller [82].

Researchers found that negative feedback for both seller and buyers on eBay are not very common, so when found they are assumed to strongly affect the reputation of the seller's cause they will be taken more seriously [82].

All above findings and much more show the role that reputation plays in the online world, especially in the stage of decision making. This factor is supported well by both computer scientists and social scientists which reveal how important and crucial the role of reputation is.

CHAPTER 8. CONCLUSION AND FUTURE WORK

8.1 Conclusion

This thesis has discussed some trust concepts, principles and definitions when looked at from social sciences point of views such as psychology, sociology, business, economic, and management, etc. in order to connect their ideas with ours as computer scientists.

I based my discussion on the model discussed in [1] and I went through the steps of trust mapping to management to making decisions explaining the factors contributing to each stage. I have used many papers from social scientist' fields in order to compare our work and results with them and come up with some new inspiring ideas for future work.

For trust mapping, I have discussed the relation between trust and experience where many papers support the idea about trust being related to experience which motivates us as computer scientists to take this step into consideration when trying to map trust. Also, I have studied the relation between trust and timing, especially the idea of forgetting factor, and it seems that we need to do more work and we also recommend more experiment from social scientists in order to answer some questions related to that matter. Furthermore, I have discussed the concept of trust content or context and how it

relates to trust mapping, and I noted that this idea is extremely important and most social scientists depend on it in evaluating trust options. This is in addition to the relation between trust and reciprocity or what we can call cooperation, and I noted the essential role it plays in trust and supported that with a small experiment. The relation between trust and reputation is also discussed as a part of the decision making stage, where the reputation is the main culprit in taking such trust decisions.

The most important part in my thesis is the discussion related to trust management represented by transitivity and aggregation. The idea of transitivity is very controversial even in the field of computer science where I mentioned how some papers consider trust transitive and others do not have the same opinion.

In the fields of social sciences, there has been a huge contribution in that matter which is supporting the idea of transitivity and its presence for the most part. I have included some research as examples and illustrations of why these social scientists think the way they do. The same applies for aggregation where I have tried to find some ideas related to the two principles related to aggregation and proposed in [1], which stems from psychological bases. Small experiments were run when applicable in order to compare our results with social scientists thoughts and come up with some useful conclusions.

8.2 Future Works

During my work I have mentioned some suggestions for future work inspired by social scientists points of view, and most of the work revolves about trying to apply what we have learned from social sciences on our work. This will make the job more accurate, thorough, concrete, and complete.

The first and foremost task is to consider the dynamic nature of trust more in our study. As I showed in previous sections, the timing factor is very important in studying trust given its dynamic and changing nature over time. However, most studies in computer science are kind of static where data was collected and studied at a specific period of time neglecting the effects that could have happened in later or previous periods. Considering this factor may open up a new whole challenge that could reveal really interesting results in that matter. Testing this concept through time can give us an idea about the effects of timing in changing trust levels. In fact, incorporating time metric in trust study could be vital in studying the effects of experience and reciprocity on trust as well. This can be done by applying some longitudinal study on the data, or by collecting different snapshots at different times and compare the results when it comes to trust levels changing over time and trying to capture the factors contributing to this change.

Furthermore, other factors I mentioned in trust mapping section should be also taken into consideration when analyzing the data such as content, and reciprocity. More work has to be done, especially when it comes to discussing reciprocity and its effects on trust, and in applying trust study on content based environment.

Another point to be improved is how we give weight to negative experiences when aggregating the different paths. Generally, more weight has to be assigned to these paths since negative experiences have more impact on the trusting decision as I discussed earlier. We may need to consider the case where bad experience drop off the trust more quickly than the good experience can build it. Thus, when having bad experience, we should give more attention to how much trust level drops.

Other work to be considered is related to the concept of forgetting factor. This may include studying its effects more in depth and playing with different thresholds in order to achieve the best results.

Also, more work has to be done in order to refine the mapping stage in the discussed model hoping to incorporate more accurate tools and metrics to capture trust between users in a better way.

Finally, studying trust is as challenging as the concept itself. Every day may bring new ideas and implementations. Also, what works for some models may not work for another and what seems to be wrong in one model may be right in another. There is no absolute rule in such matter. My goal was just to shed the light on some concepts correlated with the discussed model hoping to get a closer view to the reality.

Table 6 below summarizes some of the most important points studied and discussed through the chapters in this thesis; it shows the proposed points from social scientists points of view and what is supported in Epinions or Twitter dataset in the discussed model. Also, it lists some points and suggestions about what needs to be done for future enhancement.

Table 6. Summary of Supported Points and Future Enhancements

Inputs from Social Scientists	Included or Not in the Discussed Model?	How is it Included?	Future Enhancements to Include
TRUST AND CONTENT/CONTEXT			
Content/context of trust is important in evaluating trust relations in mapping stage.	• Partially in Twitter. • Not in Epinions.	Data collection of Twitter done from the same group.	Collect new dataset in Epinions considering the same content between users.
Content/context of trust is important in evaluating trust relations in transitivity.	• Partially in Twitter. • Not in Epinions.	Transitive triads were deduced from relations within the same group of people	Filter transitivity triads considering the same content in Epinions.
Causal attributions.	• Not in Twitter. • Not in Epinions.		Not easy to be extracted.
TRUST AND TIMING			
Role of time factor in studying trust dynamic.	• Not in Twitter. • Not in Epinions		• Find a way to study dynamic of trust; include time metric. • Perform longitudinal study of trust.
Forgetting Factor (FF).	• Yes in Twitter. • Not in Epinions.	• Discount the old experiences by Sigma factor (0.9). • The most recent experience represented by the last month.	• Incorporate (FF) in Epinions. • Experiment with different thresholds and discount weights

Table 6. Continued

Timely response effects on trust level.	• Not in Twitter. • Not in Epinions.		Try to monitor the effects of timely response between users in Twitter.
TRUST AND EXPERIENCE			
Role of experience in trust.	• Yes in Twitter. • Yes in Epinions.	• The number of interactions is used to infer experience level. • Paths with more interactions assigned higher confidence when aggregating. • Using multiplication operator to express transitivity (indirect experience is less strong than the direct one).	
TRUST AND RECIPROCITY			
Role of reciprocity in trust.	• Not in Twitter. • Not in Epinions.		• Incorporate reciprocity concept in the mapping stage of the model and capture relations in both directions.
TRUST TRANSITIVITY			
Trust transitivity.	• Yes in Twitter. • Yes in Epinions.	The model was able to predict indirect trust using transitivity concept in both datasets with small error.	

Table 6. Continued

Content/context of trust is vital to evaluate transitive trust relations	• Partially in Twitter. • Not in Epinions.		Filter transitivity triads considering the same content in Epinions.
Social context and network structure effects on trust transitivity	• Not in Twitter • Not in Epinions.		We have to pay closer attention to the social context of the relations to evaluate transitivity accurately.
FSBH theory effects on transitivity and balance.	• Partially in Twitter. • Partially in Epinions.	• Some results were consistent with FSBH in both datasets. • The number of balanced triads is higher than the imbalanced one	More work to be done to investigate reasons of inconsistent results with FSBH.
AGGREGATION			
More information from different sources about the trustee increases the confidence of trustor decision toward him.	• Yes in Twitter. • Yes in Epinions	• This is the first aggregation principle proposed for the model. • All paths are considered and aggregated on the way between the trustor ad trustees, so the model works more effectively considering different recommendations.	

Table 6. Continued

Negative information affects the level of trust more badly than the effects of positive information.	• Not in Twitter. • Not in Epinions.	Negative experiences affect the impression level and it drops.	• Look more in depth to how much drop in trust level results from negative experiences on the aggregation path. • Maybe more weight has to be given to negative experiences when aggregating results. • This requires evaluations to the importance of each path in the eye of trustor.
• Sometimes many bad experiences will break the trust forever even if faced by positive one after. • Many good experiences may save the trust forever even if faced by negative one later.	• Not in Twitter. • Not in Epinions.		Forgetting factor should have some constraints to the number of negative or positive experiences that the user can forget.
ASSIGNING WEGHTS TO DIFFERENT AGGREGATION PATHTS			
• Closest friends	• Yes in Twitter. • Yes in Epinions	Paths with higher confidence represent closer friends, so they were given more weight in making decision.	

Table 6. Continued

• Preference similarity.	• Not in Twitter. • Not in Epinions.		Look into other ways of assigning weights to the aggregation paths.
DECISION MAKING			
• Role of reputation in decision making stage	• Not in Twitter • Not in Epinions.		• Incorporate the stage of decision making in our model. • Study the role of reputation in trust in this stage.

LIST OF REFERENCES

LIST OF REFERENCES

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